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Mating System Differences and Genetic Effects for Preweaning Traits in Beef Cattle in the Gulf Coast Region of the United States.

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MATING SYSTEM DIFFERENCES AND GENETIC EFFECTS FOR PREWEANING TRAITS IN BEEF CATTLE IN THE GULF COAST REGION OF THE UNITED STATES

A Dissertation

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by
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Dedication

This manuscript is dedicated to the memory of my 'foster' mother Ms. Ida Scott. Her life was a mission of giving, and she expected no material returns. She considered her greatest reward to be the success of the many foster children she managed to raise, even though she was unable to walk. She measured success by our demonstration of responsibility, honesty, and commitment to excellence in all undertakings. I am especially grateful to her for leading me to believe in the power of Faith.

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Abstract

Preweaning data collected on 1,180 calves in generation five of a crossbreeding project were analysed. The systems involved were first-cross (F_1), three-breed terminal, two-, three-, and four-breed rotational and rotational-terminal. Angus (A), Brahman (B), Charolais (C), and Hereford (H) breeds were used in the F_1 and rotational phases, while Gelbvieh (G) and Simmental (S) were the terminal sire breeds. The traits studied were birth weight (BWT), preweaning gain (ADG), 205 d weight (WWT), and weaning height (WHT). Least squares analysis of variance procedures were used for comparisons of mating systems for all traits. Estimates of direct and maternal additive (Ig, Mg) and heterotic (Ih, Mh) genetic effects for preweaning traits for A, B, C, H and their crosses, and Ig for G and S were obtained by regression procedure. Least squares means for BWT, ADG, WWT and WHT were 33.12, .875, 213.28, kg, and 117.01 cm, respectively. The F_1, three-breed terminal, and three-breed rotational-terminal calves had larger BWT while two-breed rotational-terminal and three-breed terminal calves had larger ADG, WWT, and WHT than calves from other mating systems. Among rotational calves, BWT means were similar but two-breed rotation had larger ADG and WHT than other rotational calves. Among rotational-terminal calves, three-breed rotational-terminal had larger BWT, and two-breed rotational-terminal had larger ADG, WWT and WHT than other rotational-terminal systems. Brahman cross F_1 calves had larger means for preweaning traits than AH F_1 calves. Of the three-breed terminal calves, progeny of

BC dams had the largest means for all traits. Among three-breed rotational dams, calves from CBA and CBH breed combinations had larger ADG, WWT and WHT than calves from ABH dams. Angus Ig and Mg effects decreased ADG, WWT and WHT. Brahman Mg decreased BWT and increased all other traits, whereas MgH increased BWT and decreased all other traits. The MgC effects were positive for BWT, ADG and WWT. Simmemtal and Gelbvieh Ig effects increased ADG, WWT and WHT, with IgS being larger than IgG in all cases. Angus-Brahman and AC Ih effects increased ADG, WWT and WHT and IhBC increased WHT. MhAB increased BWT, ADG and WWT.

Chapter I

Introduction

The beef cattle industry in Louisiana is primarily a commercial cow-calf industry with weaned calves being the primary product of economic importance. The majority of these cow herds involve crossbred cattle of Brahman inheritance, because of the ability of the Brahman breed to withstand the hot and humid conditions of the Gulf Coast Region, and to tolerate internal and external parasites. Cartwright et al. (1964) in Texas, Turner and McDonald (1969) in Louisiana, and Koger et al. (1975) in Florida clearly showed that the Brahman first-cross cow is superior to other crossbred dams in fertility and maternal ability. When mated to sires of unrelated breeds the Brahman first-cross dams wean larger calves than their contemporaries.

A major disadvantage of the Brahman first-cross cow is that she does not reproduce herself, resulting in the need for replacement females to be obtained outside the herd. An alternative mating system that offers a reasonable compromise is the rotational crossbreeding system. Rotational crossbreeding systems can involve two, three, or more breeds. They are designed such that females produced in one generation are mated to the sire breed of the system that is least represented in their breed composition. This permits retention of replacement females within the system and retention of reasonable levels of heterosis, both in the progeny and in the replacement females.

Heterosis is the superiority of crossbred offspring over the mean of their parents and has been attributed to differences in gene frequency within parental types, and favorable gene combination effects for the relevant traits (Willham, 1970; Sherridan, 1981; Pirchner, 1983; Willham and Pollack 1985; Falconer, 1989). Researchers at several locations have compared two- and three-breed rotational systems that included the more common breeds in the U.S. (Crockett et al., 1978; Alenda et al., 1980; Dillard et al., 1980; Neville et al., 1984; Urick et al., 1986). However, none have compared a three-breed terminal system using Brahman first cross cows to rotational systems including the Brahman breed, or to the mating of surplus rotational cows to unrelated terminal sires.

Crossbreeding allows the producer to combine breeds that complement each other for traits of economic importance and that generate heterosis according to the degree of breed heterozygosity that results in the crosses. It is important to study various mating systems and breed combinations for traits of economic importance, so that the most ideal systems and breed combinations in a given environment or area can be identified for recommendation to commercial producers.

A long term crossbreeding study in the Louisiana Agricultural Experimental station involved Angus, Brahman, Charolais, and Herefords in two-, three-, and four-breed rotational crossbreeding systems with the restriction that each rotation combination include the Brahman breed. Comparisons among these rotational crossbreeding systems and different breed combinations within each system for preweaning traits over four generations of mating were given by Franke (1994) and Habet (1996). Generation five of this crossbreeding study included additional matings. These were the mating of purebred cows to produce Angus x Hereford, as well as Brahman first cross calves, the mating of generation five, two- three- and four -breed rotational crossbred cows each to produce rotation calves as well as calves from unrelated terminal sires. The terminal sire breeds for the three-breed and rotational-terminal crosses were Gelbvieh and Simmental.

Given the diversity of the matings in generation five, it is important to compare the various mating systems for preweaning traits and to partition the sources of genetic effects that contribute to the phenotypic variation found among the progeny. This will provide additional insights into ways of utilizing the breeds to the greatest advantage for cow-calf production in Louisiana.

The objectives of this study were to:

1. Evaluate the performance of F_1, three-breed terminal, two-, three-, and four breed rotational, and terminal rotational crossbreeding systems for preweaning traits.

2. Estimate direct and maternal additive and non-additive genetic effects for preweaning traits for the four base breeds and two terminal sire breeds.

Chapter II

Review of Literature

Introduction

Crossbreeding is widely practiced in commercial cow-calf operations to meet short term objectives for profit maximization as well as long term objectives for genetic improvement. The widespread use of this system for the production of weanling calves is fairly recent (Crockett et al., 1978) compared to its use for commercial production in plants (Shull, 1921), swine (Winters, et al. 1935), and poultry (Shoffner et al., 1966).

According to Cartwright (1970), a higher rate of genetic improvement can be expected from selection among breeds than selection within breeds for economically important traits in beef cattle. Traits of economic importance in cow-calf operations include birth weight, average daily gain, and weaning weight. Genetic diversity among breeds for these traits is a potentially valuable asset in achieving new production goals which arise from changes in market demand and in the economics of production. These objectives can be accomplished through crossbreeding to take advantage of breed complementarity and heterosis.

Heterosis, which is defined as the increased vigor in the crossbred offspring, is attributed to the assembly of favorable dominance effects at many loci for a specific trait (Cunningham, 1987). This allows the crossbred individual to perform above the average of the parents for the traits of interest. But variation among breeding groups in a crossbreeding system is due to more than heterosis as described above. Included are the transmissible effects from parents to offspring (direct additive genetic effects), the interaction of these effects in the progeny (direct heterotic effects), and the indirect effect of the dam on the performance of the offspring (maternal effects).

Maternal effects are environmental (mostly permanent) in terms of their influence on the offspring (Koch,1972). Genetically, however, they are due to the average effects of genes (maternal additive effects) and interaction effects of genes in the dam (maternal heterotic effects).

Dickerson (1969) and Koch (1972) noted that maternal effects may be influenced by the grand-maternal environment, and these can be partitioned in a similar manner as the maternal effects. However, Alenda et al. (1980) and Koch et al. (1985) reported a small and negative relationship between maternal and grand-maternal effects for preweaning traits. In most studies grand maternal effects are assumed to be negligible.

The objective of this review is to compare results of studies related to genetic effects under different mating systems and the separation of the genetic components for relevant preweaning traits in crossbred cattle. The preweaning traits in this study are birth weight, average daily gain, weaning weight adjusted to 205 d, and hip height at weaning. The main focus will be on crosses involving the breeds used in this study, namely, Angus, Brahman, Charolais, Hereford, Gelbvieh, and Simmental. Information on the terminal sire breeds Gelbvieh and Simmental is relatively limited.

With the exception of weaning hip height, the review for each trait will be divided into four sections. The first is the introductory section which will include discussion of straightbred means. The second section will be based on findings related to mating systems; the third section reports on direct and maternal additive effects while the fourth section will contain average, direct and maternal heterotic effects. The number of published reports on weaning hip height data was insufficient to justify sectional presentation for this trait.

Birth Weight

Introduction. Birth weight is a primary measure of prenatal growth (Nelson and Beavers, 1982), and is one of the first traits that can be recorded in cattle (Long, 1980: Robison, 1992). The importance of birth weight in cow-calf production is largely due to its positive genetic correlation with weaning weight (Fitzhugh et al., 1967; Vesley and Robinson, 1971; Denise et al., 1988; Koots et al., 1991; Salgado-Fonseca, 1995). In phenotypic terms, this means calves that are heavier at birth are more likely to be heavier at weaning.

Extreme values for birth weight are responsible for economic and biological losses to the producer. At the upper end of the scale losses are associated with dystocia (calving difficulty), especially in conditions of primiparity, and its consequences on calf and dam (Bellows et al., 1971; Brinks et al., 1973; Laster et al., 1973; Pascal et al., 1991). Laster and Gregory (1973) and Smith et al. (1976) cited a linear relationship between level of dystocia and birth weight. Losses at the lower end of the scale were attributed to reduction in calf vigor and performance, often resulting in increased neonatal mortality. Based on these observations, a moderate birth weight may be more desirable to avoid calf and cow losses that will affect economic returns.

Significant variation in birth weight across breeds has been reported. Invariably the ranking was Charolais, Hereford, Brahman, and Angus in descending order with Brahman and Angus exchanging rank in a few cases (Ellis et al., 1965; Turner and McDonald, 1969; Sagebiel et al., 1973; Crockett et al.,1978; Dillard et al., 1980; Wyatt and Franke, 1986).

Mating Systems and Birth Weight. Heterosis for birth weight was evaluated under first cross and backcross systems for Brahman and Hereford cattle by Cartwright el al. (1964). They reported highest levels of heterosis for backcross calves from F_1 dams followed by backcross calves from purebred cows. The lowest level of heterosis was reported for F_2 calves. They presented heterosis estimates for birth weight from first cross calves, backcross calves from first cross cows, back cross calves from purebred cows and F_2 calves of 10.0, 5.5, 8.2 and 2.0%, respectively.

Turner and McDonald (1969) studied birth weight under straight breeding, backcrossing, two-, and three-breed crossing. They reported that Angus backcross progeny had the highest birth weights. However, as a group, three-breed crosses ranked highest for birth weight. This conforms with expectations as three-breed cross progeny have 100% of both individual and maternal breed heterozygosity.

In a study comparing two generation of calves produced from backcross and two- and three-breed rotational crossbreeding systems, Chapman et al. (1970) failed to find significant differences among mating systems for birth weight. The breeds involved were Angus, Polled Hereford, and Santa Gertrudis. Two-breed rotational crosses showed highest levels of heterosis (Crockett et al., 1978). They evaluated three generations of crossbreeding involving Angus, Brahman and Hereford breeds in all possible two-breed rotational combinations. The crossbred dams included F1, reciprocal first backcross, and reciprocal second backcross. The two-breed rotational calves in this study maintained high levels of heterosis for birth weight, especially Angus-Brahman and Brahman-Angus with 15.0 and 14.0%, respectively.

Neville et al. (1984) studied performance of calves produced from purebred Angus, Polled Hereford and Santa Gertrudis bulls mated to grades and two-, and three-breed rotational cross dams of these breeds. Progeny from two-breed rotational systems had heterosis values of -1.3, 1.2 and 5.3% over the three generations, while the corresponding values for three-breed combinations were 1.9, 4.8 and 5.7%, respectively. Birth weight heterosis values increased each generation and in each generation three-breed rotational crosses had a higher level of birth weight heterosis than two-breed rotational crosses. Urick et al. (1986) also found higher heterosis values for birth weight for three- compared to two-breed rotational crosses. Their study involved Angus, Charolais and Hereford breeds. Another report ranking three-breed rotational crosses ahead of other crosses for birth weight heterosis was Olson et al. (1993). They studied mating systems involving purebred, F_1, backcross, F_2, and three-breed crossbred cows of Angus, Brahman, and Charolais breeding. The F_1 and F_2 cows produced inter se crossbred calves, backcross cows produced 3/8:5/8 calves and three-breed cows produced three-breed rotational calves. The estimate for birth weight heterosis from three-breed rotation calves was 3.7 kg.

Comerford et al. (1987) reported heterosis for birth weight of 2.2 kg ($P < .01$) for Hereford x Brahman crosses. No other significant heterotic effects were reported in the four-breed diallel system including Brahman, Limousin, Polled Hereford, and Simmental breeds.

Tinker et al. (1988) compared the performance of Gelbvieh and Limousin breeds as terminal sires mated to two-breed cross cows of Angus, Brown Swiss, Hereford, Jersey and Simmental combinations. Gelbvieh-sired calves were 1.0 kg heavier ($P < .05$) than Limousin-sired calves at birth.

Marshall et al. (1990) reported results from two-breed rotations of Angus, Hereford and Simmental cattle. They found that within the Simmental x Hereford rotation, calves from Hereford backcross cows mated to Simmental sires averaged 1.7 kg heavier at birth than Simmental backcross cows mated to Hereford sires. Additionally, within the Angus x Hereford rotation, calves from Hereford backcross cows mated to Angus sires averaged 0.9 kg heavier at birth than calves from Angus backcross cross cows mated to Hereford sires. This emphasized differences in calf performance based on the source of the maternal genes.

Gregory et al. (1991a) studied the effects of heterosis in F_1 through the F_4 generations of nine parental breeds forming three composite populations. They reported that among two year old dams, F_2 and F_3 calves had the highest heterosis for birth weight across populations, whereas among three year old dams the highest heterosis level for birth weight, 2.5 kg, was found for F_1 calves. These results demonstrated an interaction effect between age of dam and generation for birth weight heterosis.

For generations one to four of the current study. Habet (1996) reported birth weight heterosis levels of 1.1, 0.96 and 2.4 kg for two-, three-, and four-breed rotation calves, respectively. The heterosis levels for the two- and three-breed rotation calves were similar while that of the four-breed rotation was greater ($P < .05$).

Direct and Maternal Additive Effects on Birth Weight. Direct and maternal additive effects on birth weight varied by breed and location. Direct additive effects of the Angus breed for birth weight were generally less than the direct additive effects of other breeds to which it was compared. This observation was demonstrated in the many instances reporting Angus direct additive effect on birth weight deviated from Hereford effect, in which values ranged from -5.9 to -1.2 kg ($P < .01$) (Gregory et al., 1965: Gaines et al, 1970; Gregory et al., 1978b; Alenda et al., 1980; Dillard et al., 1980; Vaamonde and Franke, 1984; Koch et al., 1985; Morris et al., 1986; Wyatt and Franke, 1986; Cunningham and Magee, 1988). However, they reported no difference between the Angus and Hereford maternal additive effects on birth weight.

Comparisons of Angus with other breeds for direct additive effects on birth weight followed the same pattern. Gaines et al. (1970) reported -2.4 kg and 1.0 kg for direct additive effects of Angus and Shorthorn, respectively. Additionally Gregory et al. (1965) reported -2.9 kg for the direct additive effect on birth weight for Angus compared to Simmental, while Olson et al. (1993) reported values of 6.0 and 13.0 kg for direct additive effects of Brahman and Charolais respectively, compared to Angus. A slight variation to this trend was the study of Neville et al. (1984), in which -1.18 kg was recorded as the direct additive effect of Angus relative to Polled Hereford, but this difference was not significant.

Olson et al. (1985) and Wyatt and Franke (1986) found maternal additive effects on birth weight of 4.6 and 4.8 kg for Brown Swiss deviated from Angus ($P < .01$). These values were comparable to the 2.78 kg reported by Spelbring et al. (1977) for the maternal additive effect on birth weight of Milking Shorthorn relative to Angus.

The direct additive effects of Brahman on birth weight relative to Angus and Hereford were mostly significant and positive, as opposed to the negative Brahman maternal additive effects, relative to these two breeds, (Vaamonde and Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986; Olson et al., 1993). Comerford et al. (1987) obtained a positive but non-significant direct additive effect of Brahman on birth weight, relative to Hereford, but the maternal additive effect was negative ($P < .01$). The largest estimated genetic effect reported by Roberson et al. (1986) was the

Brahman x Hereford maternal additive deviation of -7.4 kg. However, the figures presented in a report by Wyatt and Franke (1986), suggest no significant difference between the Brahman - Angus and Brahman - Hereford maternal additive effects on birth weight.

The Charolais direct additive effect on birth weight relative to Angus and Hereford was positive with values of 3.4 to 4.0 kg (Alenda et al., 1980; Dillard et al., 1980; Wyatt and Franke, 1986; Olson et al., 1993). The maternal additive influence of Charolais tended to decrease birth weight. Sagebiel et al. (1973) and Olson et al. (1993) reported no difference between maternal additive effects of Charolais and Angus, while Dillard et al. (1980) cited a 1.4 kg advantage for Charolais over Angus in maternal additive effect on birth weight. Wyatt and Franke (1986) reported a birth weight maternal additive effect of Charolais relative to Angus of -2.6 kg.

Alenda et al. (1980) and Comerford et al. (1987) reported negative direct additive effects of Hereford on birth weight. The direct additive effect of Hereford on birth weight was generally lower than that of Charolais and higher than that of Angus (Dillard et al., 1980; Wyatt and Franke, 1986). The maternal additive effects of Hereford tended to decrease birth weight (Dillard et al., 1980; Wyatt and Franke, 1986), although Alenda and et al. (1980) and Comerford et al. (1987) reported positive maternal additive effects on birth weight for the Hereford breed. Neville et al. (1984) reported a larger ($P < .05$) maternal additive effect of Polled Hereford on birth weight than the maternal additive effect of Santa Gertrudis.

These results emphasize the importance of careful breed selection to meet desired objectives for birth weight in a crossbreeding program. The genetic differences allow selective matching of complementary breed types to the environment.

Average, Direct and Maternal Heterotic Effects on Birth Weight. Average heterosis values for birth weight usually lacked statistical significance (Chapman et al., 1970; Sagebiel et al., 1973; Dillard et al., 1980; Long, 1980; Koch et al., 1985; Sacco et al., 1989; Olson et al., 1993). Even when significant heterosis was reported for birth weight the values were still low (Gaines et al., 1966; Crockett et al., 1978; Gregory et al., 1978a; Comerford et al., 1987). Pahnish et al. (1969) reported negative values of heterosis for birth weight.

Brahman-Hereford crosses tended to have relatively high levels of heterosis for birth weight (Brown et al., 1967). Levels up to 14.5% have been reported (Cartwright et al., 1964; Pahnish et al., 1969; Sagebiel et al., 1974; Long and Gregory, 1974; Comerford et al., 1987). In a review of heterosis estimates for preweaning traits in Brahman cross calves Franke (1980) reported an average heterosis of 3.3 kg for F_1 calves and 1.9 kg for calves from Brahman first-cross cows.

Gregory et al. (1991a) reported constant rates of heterosis for birth weight for F_1 to F_4 generations of crosses involving Bos taurus breeds. Pahnish et al. (1969) and Smith et al. (1976) found largest birth weights for Charolais crosses. They reported average heterosis for birth weight of 12.4% and 9.0% respectively; and these were associated with higher rates of dystocia as concurred by Dhuyvetter et al. (1985). Gregory et al. (1978a) reported a birth weight heterosis of 1.3 kg for Angus x Hereford calves, in a study involving various two-breed combinations of Angus, Brown Swiss, Hereford, and Red Poll. This was in agreement with the 1.55 kg reported by Laster et al. (1973) for Hereford x Angus calves.

Direct and maternal heterotic effects on birth weight were generally low in accordance with the low average heterotic effects. Direct heterosis effects of Angus crosses ranged from -3.2 to 3.5 kg (Gregory et al., 1978b, Alenda et al., 1980; Dillard et al., 1980; Knapp et al., 1980; Vaamonde and Franke, 1984; Morris et al., 1986; Wyatt and Franke, 1986; Olson et al., 1993). The lowest value for direct heterosis on birth weight of crosses involving Angus was recorded for Angus x Hereford cross (Alenda et al., 1980). The highest value was for an Angus x Brahman cross (Vaanonde and Franke, 1984). Olson et al. (1993) also reported a relatively high estimate for Angus x Brahman direct heterosis effect on birth weight compared to other crosses in their study. This highlights a general pattern in which crosses between Angus and other *Bos taurus* breeds had lower direct heterotic effects on birth weight than the Angus x Brahman cross.

Maternal heterosis effects on birth weight for crosses with Angus ranged from -1.3 to 2.9 kg (Alenda et al., 1980; Knapp et al., 1980; Vaamonde and Franke, 1984; Koch et al., 1985; Morris et al., 1986; Wyatt and Franke, 1986; Olson et al., 1993). The Angus x Hereford cross had lower estimate for the direct heterotic effect on birth weight than for other crosses involving Angus Alenda et al. (1980) while the highest value was for the Angus x Brahman cross (Olson et al., 1993). One notable deviation from this general trend was a 3.5 kg maternal heterosis effect (P < .01) on birth weight for Angus x Hereford reported by Vaamonde and Franke (1984) while the Angus x Brahman maternal heterosis effect on birth weight was not significant.

Direct heterotic effects of Brahman crosses varied depending on other breeds in the combination. For Brahman x Hereford and Angus x Brahman crosses the direct heterotic effects on birth weight were positive and mostly significant, ranging from 2.0 to 3.5 kg (Vaamonde and Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986; Comerford et al., 1987). However Wyatt and Franke (1986) and Olson et al. (1993) reported -0.3 and -0.2 kg, respectively for the Brahman x Charolais direct heterosis effect on birth weight. Maternal heterosis effects on birth weight for Brahman crosses were not different from other crosses as reported by Dearborn et al. (1987). Most values reported for maternal heterosis effects on birth weight, for crosses including the Brahman breed, involved crosses with Angus and Hereford and were positive and significant (Vaamonde and Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986).

Several reports showed birth weight direct and maternal heterosis estimates for Charolais crosses to lack statistical significance (Alenda et al., 1980; Dillard et al., 1980; Knapp et al., 1980; Olson et al., 1993). However, Wyatt and Franke (1986) reported -1.7 kg (P < .01) for the direct heterosis effect on birth weight of both Angus x Charolais and Charolais x Hereford crosses. Maternal heterosis effects on birth weight for the same crosses, were also significant at 1.0 and 1.08 kg, respectively.

Neville et al. (1984) reported non-significant direct heterosis effects on birth weight of 0.2 and 0.8 kg, respectively, for Angus x Polled Hereford and Polled Hereford x Santa Gertrudis cattle. Reports of direct heterosis effects on birth weight for Hereford crossed with Angus tended to be low compared to values for Hereford crossed with Brahman, while the values for Hereford crossed with Charolais were negative (Gregory et al., 1978b; Alenda et al., 1980; Dillard et al., 1980; Wyatt and Franke, 1986). Maternal heterosis effects on birth weight of Hereford crossed with Angus were negative in some cases (Alenda et al., 1980; Knapp et al., 1980; Wyatt and Franke., 1986) and positive in others (Vaamonde and Franke, 1984; Marshall et al., 1990).

These reports underscore the importance of heterotic effects on birth weight, whether as a direct effect on the calf or indirectly through the maternal environment. The effects varied with breed combinations, thus emphasizing the importance of careful breed selection for crossbreeding programs. It is imperative that sire breeds be selected carefully to avoid dystocia.

Preweaning Average Daily Gain

Introduction. Preweaning average daily gain (ADG) is an expression of units of weight gained per day of calf age. The average daily gain from birth to weaning is influenced by the maternal contribution to early postnatal growth as well as by the genetic potential of the calf. The maternal contribution of the dam is largely the dams milking and mothering abilities that affects the expression of the genetic potential of the calf. The performance of the dam in this role is controlled by her own genes for these traits as well as the environment in which she is required to function.

Preweaning average daily gain of Charolais was shown to be greater than Angus, Brahman, and Hereford (Pahnish et al. 1969; Sagebiel et al. 1974; Jain et al., 1971; Wyatt and Franke, 1986). The Angus ADG was larger than Hereford (Long and Gregory, 1974; Dillard et al., 1980; Koch et al., 1985).

Mating Systems and Preweaning Average Daily Gain. Mating system was reported to be a significant source of variation in heterosis estimates for ADG even when the same breeds were involved in the crosses. Cartwright et al. (1964) studied mating systems involving Brahman and Hereford cattle. They reported average daily gain heterosis values for F_1 and F_2 calves of 11 and 9.5%, respectively. Additionally, Hereford backcross calves had average daily gain heterosis of 12% while the average daily gain heterosis estimate Brahman backcross calves was not different from zero. Turner and McDonald (1969) reported ADG larger heterosis values for three-breed cross calves than for backcross calves. Chapman et al. (1970) found that average daily gain heterosis estimate was larger for two-breed rotational than for three-breed rotational and backcross calves.

Sagebiel et al. (1974) studied heterosis for preweaning average daily gain in two-breed cross calves using Angus, Charolais, and Hereford as base breeds. They reported that heterosis estimates were highest for Angus x Hereford first-cross calves (6.9%), while heterosis estimates across rotational matings for ADG averaged 3.5 and 4.3%, respectively, for males and females. These results are not surprising since maximum heterosis is anticipated in the first cross.

Three-breed rotation calves ranked higher for average daily gain heterosis than two-breed rotation calves in each of three generations reported by Neville et al. (1984). Their study involved two- and three-breed combinations of Angus, Polled Hereford, and Santa Gertrudis. They reported that among two-breed rotations the Hereford x Santa Gertrudis cross ranked highest for ADG heterosis. Urick et al. (1986) also found that on the average calves of three-breed rotational system exceeded ($P < .01$) two-breed rotation calves in preweaning average daily gain heterosis. Among two-breed rotations, Hereford-sired calves exceeded Angus- and Charolais-sired calves in average daily gain. Additionally, backcross calves exceeded ($P < .01$) two-breed rotation calves in average daily gain heterosis but did not differ from three-breed rotation calves.

Nelson et al. (1982) reported that three-breed cross calves nursing F_1 Angus x Hereford, Brown Swiss x Hereford and Charolais x Hereford dams gained .12 kg/d more ($P < .01$) than F_1 calves nursing Hereford dams. This is indicative of increased maternal ability of crossbred dams over Hereford dams.

Marshall et al. (1990) studied two-breed combinations of Angus, Hereford, and Simmental cattle. They reported that within Simmental x Hereford rotations calves from Simmental backcross cows gained .058 kg more per day than calves from Hereford backcross cows. Also, within Angus x Hereford rotations, calves from Angus backcross cows gained .028 kg/d more than calves from Hereford backcross cows.

Direct and Maternal Additive Effects on Preweaning Average Daily Gain. Gregory et al. (1978b) reported .05 and .04 kg for breed direct and maternal additive effects, respectively, on ADG for Angus as a deviation from Hereford cattle. An Angus advantage over Hereford for the direct additive effect on ADG was also reported by Cunningham and Magee (1988). Most other researchers reported no significant difference in direct additive effects on ADG of Angus relative to Hereford (Dillard et al., 1980; Vaamonde and Franke, 1984; Morris et al., 1986; Wyatt and Franke, 1986). However, Koch et al (1985) reported -.02 kg for the direct additive effect on ADG of Angus versus Hereford. For maternal additive effects on ADG of Angus relative to Hereford, all reports showed an Angus advantage with values ranging from .02 to .12 kg/d (Gregory et al., 1978c; Dillard et al., 1980; Vaamonde and Franke, 1984; Koch et al., 1985; Morris et al., 1986; Wyatt and Franke, 1986; Cunningham and Magee, 1988). Olson et al. (1985) found that the Angus direct and maternal additive effects on ADG were less ($P < .01$) than the Brown Swiss effect by 0.11 and 0.13 kg/d, respectively.

Vaamonde and Franke (1984), Roberson et al. (1986), Wyatt and Franke (1986), and Comerford et al. (1988) reported negative values (-.02kg/d in each case) for direct additive effects on preweaning average daily gain of Brahman compared to Angus and Hereford. However reports for maternal additive effects on preweaning average daily gain showed the reverse trend. The maternal additive effect of Brahman significantly increased preweaning average daily gain over the maternal additive effects of Angus and Hereford (Vaamonde and Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986; Comerford et al., 1988). These results indicate that the Brahman maternal influence is more conducive to preweaning growth than the maternal influence of Angus and Hereford.

Notter et al. (1978b) found a negative (-.017 kg/d) maternal additive genetic effect on ADG for Charolais compared to Angus and Hereford. Dillard et al. (1980) reported .08 kg/d and 1.3 kg/d for direct additive and maternal additive genetic effects on average daily gain respectively of Charolais relative to Hereford. Wyatt and Franke (1986) reported positive and highly significant direct additive effects on preweaning average daily gain for Charolais compared to Angus but the difference (.03 kg) in maternal additive effects was not significant.

Neville et al. (1984) reported that the direct additive effect of Polled Hereford was greater ($P < .05$) than that of Angus by .021 kg/d over three generations. However, Angus exceeded Hereford in maternal additive affects on preweaning average daily gain, and the difference increased with advancing generations to reach .031 kg in generation three. The Polled Hereford direct and maternal additive effects on preweaning average daily gain were less ($P < .01$) than that of Santa Gertrudis.

Average, Direct and Maternal Heterotic Effects on Average Daily Gain. There were numerous illustrations of the significance of heterosis for preweaning average daily gain (Cartwright et al., 1964; Gregory et al., 1965; Gaines et al., 1966, 1978; Pahnish et al., 1969; Chapman et al., 1970; Sagebiel et al., 1974; Smith et al., 1976; Peacock et al., 1981; Neville et al., 1984; Roberson et al., 1986). There were wide variations in the estimates depending on the breed combinations involved with more divergent types producing larger estimates.

Cartwright et al. (1964) reported preweaning average daily gain average heterosis estimates of 17.2 and 10 % for steers and heifers, respectively, produced by Brahman x Hereford crossbred calves. Gregory et al. (1965) found that Hereford x Angus and Hereford x Shorthorn calves gained more than straightbreds by .03 and .05 kg/d. respectively. Similar values for preweaning average daily gain heterosis were reported by Chapman et al. (1970). Long and Gregory (1974) and Smith et al. (1976) for Angus x Hereford calves.

Pahnish et al (1969) and Sagebiel et al (1974), respectively, reported heterosis estimates for preweaning average daily gain for steers of Angus x Charolais, Angus x Hereford, and Hereford x Charolais crosses of .067 (7.1%) and .019 kg (2.7%); .064 (7.7%) and .037 kg (5.8%); .064 (7.0%) and .016 kg (2.3%). Heterosis estimates for heifers in the report by Pahnish et al. (1969) did not differ from zero, while Sagebiel et al. (1974) reported preweaning average daily gain for the crossbred calves of .032 (4.9%), .041(6.9%), and .01kg (2.9%), respectively.

Average daily gain heterosis estimates ranged from 3.8 to 19% with the highest ($P < .01$) being for Angus x Brahman first cross calves compared to Brahman x Charolais and Angus x Charolais, according to Peacock et al. (1982). Wyatt and Franke (1986) also found higher average daily gain heterosis for Brahman and Brahman influenced crosses.

Reports of heterosis components on preweaning average daily gain generally showed positive and significant Angus x Hereford maternal heterosis effects (Gregory et al., 1978b; Dillard et al., 1980; Knapp et al., 1980; Gregory et al., 1978d; Vaamonde and Franke, 1984; Wyatt and Franke., 1986). The direct heterosis effects on preweaning average daily gain in these studies for Angus x Hereford calves ranged from .05 to .051 kg/d, while the maternal heterosis effects of Angus x Hereford dams ranged from .014 to .03 kg/d. Olson et al. (1985) reported a preweaning average daily gain maternal heterosis for Angus x Brown Swiss cattle of .04 kg/d ($P < .01$).

Direct and maternal heterotic effects of Brahman-cross calves and dams on preweaning average daily gain were positive and significant. Vaamonde and Franke (1984) reported .10 and .11 kg/d for direct heterosis effects on preweaning average daily gain for Angus x Brahman and Brahman x Hereford, respectively. Corresponding values for maternal heterosis effects in the report were .09 and .13 kg/d, respectively. Roberson et al. (1986) reported .02 and .022 kg/d, respectively, for direct and maternal heterotic effects of Brahman x Hereford on preweaning average daily gain. Wyatt and Franke (1986) obtained direct heterosis effects on preweaning average daily gain for Angus x Brahman, Brahman x Charolais, and Brahman x Hereford of .10, .089, and .099 kg/d respectively ($P < .01$) and maternal heterosis effects for Angus x Brahman and Brahman x Hereford of .052 and .081 kg/d, respectively.

Charolais crosses exhibited variable effects on preweaning average daily gain. Wyatt and Franke (1986) reported large positive ($P < .01$) direct heterotic effects of Charolais x Brahman crosses for preweaning average daily gain. However they found that the direct heterotic effects of Charolais x Angus and Charolais x Hereford on average daily gain were not significant. Dillard et al. (1980) reported that the Charolais x Hereford heterosis effect on preweaning average daily gain was not significant, but the Charolais x Angus direct heterosis effect (.05 kg/d) was significant. Neville et al. (1984) reported direct heterosis effects for preweaning average daily gain of .051, .033 and .102 kg/d for Angus x Polled Hereford, Angus x Santa Gertrudis and Polled Hereford x Santa Gertrudis, respectively, averaged over three generations.

Weaning Weight

Introduction. Weaning weight is one of the most important traits in beef cattle (Robison, 1992), particularly in cow-calf operations since it measures the major product of the herd. The trait has low to moderate heritability making it an ideal target for improvement through crossbreeding. Lowly heritable traits show faster rate of improvement through crossbreeding than through intra-breed phenotypic selection.

A standard calf weaning age of 205 d is recommended in the Guidelines for Uniform Beef Improvement manual (BIF, 1997). However it is impractical to weigh each calf at 205 d, therefore producers usually wean all calves the same day and adjust this weight to a 205 d equivalent using the following formula:

(((Weaning weight - birth weight)/weaning age) x 205d) + birth weight.

In some of the earlier reports weaning weight was adjusted to 180, 200 or 210 day equivalents. Although weaning weights are currently adjusted to 205 d equivalent, a comprehensive review of the literature will be made relative to weaning weight studies irrespective of the adjustment factor.

A large amount of variation in weaning weight was observed across breeds and references. In a number of cases higher weaning weight was observed for Angus calves than for Brahman and Hereford calves (Pahnish et al., 1969; Sagebiel et al., 1973; Long and Gregory, 1974; Alenda et al., 1980; Dillard et al., 1980; Koch et al., 1985; Wyatt and Franke, 1986). The ranking of Brahman calves for weaning weight compared to Angus and Hereford in these studies was not consistent. Cartwright et al. (1964), Ellis et al. (1965), and Commerford et al. (1988) reported higher weaning weight for Brahman calves than for Hereford calves. McElhenney et al. (1986) observed higher weaning weights for Brahman than Angus and Hereford calves. Wyatt and Franke (1986) found that Brahman calves had the lowest weaning weight among breeds, including Angus and Hereford. Differences in the ranking of Brahman calves for weaning weight may reflect genotype by environment interactions.

Mating Systems and Weaning Weight. Cartwright et al. (1964, 1975) reported heterosis estimates for weaning weight adjusted to 180 d for Brahman x Hereford first-cross calves of 15.9%, while F_2 calves had a higher heterosis (17.2%). Additionally, weaning weight heterosis estimates for backcross calves produced from purebred and first-cross dams, respectively, were 9.3 and 18.8%. The extra heterosis from calves of crossbred dams can be attributed to the maternal component.

Crockett et al. (1978) reported heterosis estimate for calves produced in two-breed rotational crossbreeding systems involving Angus, Brahman and Hereford breeds. They found that the calves produced in these two-breed rotations maintained a high level of heterosis for three generations. The heterosis estimates for generations one to three were 15.0, 19.0 and 17.0%, respectively.

Urick et al. (1986) compared two- and three-breed rotational crossbreeding systems involving Angus, Charolais and Hereford calves. The weaning weight heterosis estimates in this study were 4.4 and 6.6% for two- and three-breed rotations, respectively. Freedman et al. (1982) and Frahm and Marshall (1985) found that weights were higher for three-breed cross calves than two-breed cross calves; and for Simmental x Hereford cross than Angus x Hereford reciprocal cross calves.

Olson et al. (1993) observed that calves produced by three-breed cross dams exhibited the highest levels of heterosis for weaning weight, while F_3 calves showed no heterosis for weaning weight. This lack of heterosis for weaning weight in F_3 calves was also reported by Sacco et al. (1989).

Direct and Maternal Additive Effects on Weaning Weight. In a large majority of reports, positive maternal additive effect on weaning weight, for Angus compared to Hereford, were accompanied by negative direct additive effects, thus favoring Hereford over Angus for the direct additive genetic component, and establishing an Angus superiority over Hereford for the maternal additive component (Dillard et al., 1980; Vaamonde and Franke, 1984; Koch et al., 1985; Morris et al., 1986; Wyatt and Franke, 1986; Cunningham and Magee, 1988). The direct and maternal additive effects on weaning weight, of Angus relative to Hereford, in these studies ranged from -1.6 to 18.4 kg and 8.0 to 13.9 kg, respectively. However, Gregory et al. (1978b) and Alenda et al. (1980) reported no significant difference between Angus and Hereford direct additive effects for weaning weight, but they concurred with the Angus superiority over Hereford for maternal additive effects on weaning weight (8.5 and 9.8 kg, respectively).

Peacock et al. (1981) failed to find significance for the direct and maternal additive effects of Angus on weaning weight. MacNeil et al. (1982) reported that the maternal additive effect of the Angus breed on weaning weight, was less ($P < .01$) than that of Charolais and greater ($P < .01$) than that of Shorthorn and Hereford, in a study involving nine other breeds.

Peacock et al. (1981) reported a significant decrease in weaning weight (-26.6 kg) due to the direct additive effect of Brahman while the maternal additive effect (7.8 kg) significantly increased weaning weight compared to Angus and Charolais. This pattern was supported by Roberson et al. (1986) who reported -12.9 and 13.1 kg for direct and maternal additive genetic effects, respectively, of Brahman relative to Hereford. However, Vaamonde and Franke (1984) found a highly significant positive direct additive effect of Brahman relative to Angus on weaning weight while the maternal additive difference was not significant. This contrasted with observations by Wyatt and Franke (1986) and Comerford et al. (1988) who found no differences among the direct additive effects of Brahman relative to Angus and Hereford on weaning weight. The maternal additive effect of Brahman on weaning weight was greater ($P < .01$) than that of Angus (Wyatt and Franke, 1986).

Alenda et al. (1980) reported large ($P < .01$) positive direct and maternal additive effects of Charolais on weaning weight compared to Angus and Hereford. This was supported by Dillard et al. (1980) who reported 20.1 and 28.6 kg for direct and maternal additive effects on weaning weight of Charolais relative to Hereford. Peacock et al. (1981) also reported large positive direct additive (29.6 kg) but negative maternal additive effects (-6.1 kg) of Charolais on weaning weight compared to Angus. The direct and maternal additive effects of Charolais relative to Angus was 42.0 and 4.1 kg respectively, according to Wyatt and Franke (1986).

The Hereford direct additive effect on weaning weight was larger than that of Angus and Brahman and less than Charolais in many instances (Gregory et al, 1978b; Alenda et al., 1980; Dillard et al., 1980; Vaamonde and Franke, 1984; Koch et al., 1985; Roberson et al., 1986; Wyatt and Franke, 1986). However, MacNeil et al.

(1982) reported a lower value for the direct additive effect on weaning weight for Hereford than for Angus. Neville et al . (1984) reported -5.5 and 21.1 kg for direct and 4.7 and 16.2 kg for maternal additive effects on weaning weight of Angus and Santa Gertrudis respectively as deviations from the Polled Hereford effects.

Average, Direct and Maternal Heterotic Effects on Weaning Weight. The reported range of heterosis for weaning weight was 1.9 to 18.8 kg (Pahnish et al., 1969; Sagebiel et al., 1974; Drewery et al, 1978; Bailey, 1981). Differences were due to breed combination and sex of calf. Pahnish et al. (1969) observed that the weaning weight heterosis estimate for female calves was not different from zero, while steers exhibited 3.8 % ($P < .05$) heterosis for weaning weight. Their study involved Angus, Brown Swiss, Charolais and Hereford breeds. They reported that crosses including Charolais had the largest heterosis values.

Cartwright et al. (1964), Gray et al. (1978), and Gregory et al. (1978b) reported significant weaning weight heterosis for female calves but the values were lower than those for steers. In contrast to that of the report by Pahnish et al. (1969), these studies showed higher weaning weight heterosis for Angus x Hereford crosses than for crosses involving Charolais. Sagebiel et al. (1974), however studied weaning weight in an Angus, Charolais and Hereford diallel mating system and reported mean heterosis values of 3.2 and 3.8 % for males and females, respectively. According to the report by Peacock et al. (1978), the heterotic effect of Angus x Charolais (2.1%) was not significant, but the heterotic effects for Angus-Brahman (7.1%) and

Brahman-Charolais (12.2%) were significant. Brahman-Angus crossbreds had 23.2% heterosis for weaning weight in a study by Reynolds et al. (1982). There was a general tendency for higher heterosis levels in *Bos taurus-Bos indicus* crosses than for crosses among *Bos taurus* breeds (Urick et al., 1986; Comerford et al., 1988; Olson et al., 1993).

Most reports agreed on a significant and positive Angus x Hereford direct and maternal heterosis effect on weaning weight (Gregory et al., 1978b; Koch et al., 1985; Vaamonde and Franke, 1984; Morris et al., 1986; Wyatt and Franke, 1986). However, Alenda et al. (1980) reported -12.5 and -0.9 kg for direct and maternal heterotic genetic effects, respectively, for Angus x Hereford cattle. Some reports showed no significant direct heterosis for Angus x Charolais on weaning weight (Alenda et al., 1980; Peacock et al., 1981; Wyatt and Franke, 1986). However, Alenda et al. (1980) and Peacock et al. (1981) found significant maternal heterosis effects for Angus x Charolais on weaning weight.

There was complete agreement for high Angus x Brahman direct (21.2 to 25.0 kg) and maternal (13.2 to 29.8 kg) heterotic effects on weaning weight in many reports (Peacock et al., 1981; Vaamonde and Franke, 1984; Wyatt and Franke, 1986). In fact, the direct and maternal heterotic effects of Brahman combined with all other breeds were positive. Peacock et al. (1981) reported 16.5 and 18.7 kg for the Brahman x Charolais direct and maternal heterotic effects on weaning weight, respectively. Vaamonde and Franke (1984), Roberson et al. (1986) and Wyatt and

Franke (1986) found that the direct and maternal heterotic effects of Brahman x Hereford increased weaning weight by 25.2, 21.6, and 23.8 kg; and 28.2, 19.8 and 17.7 kg, respectively.

The Charolais x Hereford direct heterotic effect on weaning weight was found to be non-significant by Alenda et al. (1980) and Wyatt and Franke (1986). However Dillard et al. (1980) reported a value of 9.5 kg ($P < .05$) for the direct heterotic effect of Charolais x Hereford on weaning weight. The maternal heterotic effect of Charolais x Hereford on weaning weight was not significant in the reports by Alenda et al. (1980) and Knapp et al. (1980), while, Wyatt and Franke (1986) reported an estimate of 7.5 kg ($P < .01$) for the Charolais x Hereford maternal heterotic effect on weaning weight.

Neville et al. (1984) reported 10.7, 7.8 and 21.8 kg for the Angus x Polled Hereford, Angus x Santa Gertrudis and Polled Hereford x Santa Gertrudis direct heterotic effects, respectively, on weaning weight. With few exceptions these reports showed that direct and maternal heterosis increased weaning weight and the more consistent effects came from crosses involving Brahman cattle.

Hip height

There are very few published studies reporting genetic components for hip height, thus, the format for review of this trait is unique. The ratio of weight to hip height has been suggested as an objective measure of condition score and is positively correlated with yearling weight (Hord et al., 1986; Comerford et al., 1988).

Baker et al. (1989) used a five breed diallel mating system to study pubertal traits in heifers. They reported a mean weaning hip height of 104.9 cm for purebred cattle. The weaning hip height for each purebred as a deviation from this mean, was -2.8, 2.9, -2.7, 4.3 and -1.6 cm, for Angus, Brahman, Hereford, Holstein, and Jersey, respectively. Additionally they found that Holstein and Brahman crosses were taller than Jersey, Angus, and Hereford crosses across all ages. Average heterosis in this study was 1.9 cm ($P < .01$) or 1.8 %.

Sacco et al. (1989) reported results from two generations of the same diallel matings involving Angus, Brahman, Hereford, Holstein, and Jersey with straightbred and crossbred dams mated to Charolais and Red Poll as terminal sire breeds. They found that Charolais-sired calves were 3.6 cm taller ($P < .01$) at weaning than Red Poll-sired calves. Among straightbred dams, Holsteins weaned the tallest calves and Hereford dams weaned the shortest calves. Within crossbred dams, Brahman x Holstein F_1 and F_2 cows produced the tallest calves at weaning.

Kress et al. (1990) estimated maternal heterosis using Hereford, Angus x Hereford, Simmental x Hereford, Hereford x Simmental x Hereford and Simmental x Hereford x Simmental dam groups. They reported that Simmental sired dams produced calves with the greatest hip height at weaning. The values for hip height at weaning were 110.7 and 111.0 cm for Simmental x Hereford and Simmental backcross dams, respectively. The Angus x Hereford (107.4 cm) and Hereford backcross dams produced calves with intermediate hip heights (108.3 cm) at weaning.

Hereford dams produced calves with an average hip height of 105.9 cm. They found no differences in weaning hip height due to sex of calf with values of 107.6 and 109.8 cm for females and males, respectively.

Brown et al. (1993) studied preweaning data in 486 Angus x Brahman and reciprocal cross calves managed on common bermudagrass or endophyte infected tall fescue. They reported that weaning hip height of males was greater ($P < .01$) than that of females, the respective values being 113.2 and 110.7 cm. However, there was no difference in average heterosis for hip height between the sexes. Overall heterosis for weaning hip height was 4.2 cm ($P < .01$). Additionally, they noted an interaction of direct and maternal effects with forage environment. Calves from Angus dams seemed to receive a maternal advantage ($P < .05$) on bermudagrass over calves from Brahman dams, but on tall fescue the maternal effects of the two breeds were similar. Maternal heterosis for Angus - Brahman was 2.7 cm on bermudagrass and 1.7 cm on tall fescue. These researchers also found that calves from Brahman sires received a direct breed advantage on both forages, but the difference was greater on bermudagrass.

Paschal et al. (1995) studied postweaning data for calves from Hereford dams, sired by five *Bos indicus* and one *Bos taurus* breed of sires. They reported weaning hip height by sire breed of 122.2, 122.3, 124.4, 123.6, and 123.8 cm for Angus, Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman, respectively. Thus, Angus x Hereford calves had lower ($P < .05$) hip heights than *Bos indicus* x *Bos taurus* crosses. Among *Bos indicus*-sired calves, Indu-Brazil, Nellore, and Red Brahman crosses were taller than Gir and Gray Brahman crossed calves. These rankings were consistent with earlier report for the same breeds (Paschal et al., 1991).

Conclusions

The average performance of a group of animals is determined by their genetic makeup and by the environmental conditions in which they are kept. Under varying environmental conditions different genes may influence the phenotype, or the relative contribution of each gene might change. The basic objective of beef cattle crossbreeding system is to utilize both additive and non-additive effects of genes for improvement of mean performance of the herd.

Preweaning growth traits of calves are among the more important parameters for evaluating cattle. In commercial cow-calf operations these traits are of economic importance to producers, thus providing adequate justification for emphasis in research and development programs.

The contribution of breed complementarity and heterosis to improvement in preweaning traits was evident in the superior performance of crossbreds over purebreds. This improved performance follows increased heterozygosity. For birth weight, the direct additive effect of Brahman was large and positive while the maternal additive effect was negative. These results indicate the potential of the Brahman dam to reduce birth weight, while the direct additive effect of Brahman increased birth weight. The heterotic effects of Brahman combinations tended to increase all traits. This phenomenon is responsible for its widespread use in crossbreeding programs in the majority of herds in subtropics.

As with other commercial operators, the cow-calf producer is usually interested in net returns to investment. In several instances three-breed cross calves exceeded two-breed cross calves in performance for preweaning traits. This can be explained by the maternal heterosis to which three-breed cross calves have access. Maternal heterosis is thought to increase milk production in crossbred dams over the milk production level of their purebred counterparts, giving the three-breed cross calves an environmental advantage for growth. The economic advantage of this increase is not clear.

Angus and Hereford are the British breeds with largest numbers in the United States. Many reports have documented maternal superiority of Angus over Hereford. This was generally reflected in a higher maternal additive effect of Angus over Hereford for most traits. However the direct additive effect of Hereford was often higher than that of Angus.

This review also documented variation in results based on location of the study. This suggests the possibility of a genotype x environment interaction for genetic effects.

Chapter III

Materials and Methods

Introduction

Crossbreeding programs that are well planned at the beginning can provide an adequate information base on which to design subsequent breeding strategies. Among other factors, the value and impact of a crossbreeding study depend on the nature of the analysis conducted. The accuracy of estimated effects depend on the design of the study and the statistical model applied.

Several researchers have provided interpretation of the genetic effects derived from different mating systems (Trail et al., 1982; Eisen et al., 1983; Newman et al., 1986), while Gregory and Cundiff (1980) presented a comprehensive evaluation of crossbreeding systems. Additionally, Dickerson (1969, 1973) published information relevant to obtaining the joint effects of breed complementarity and heterozygosity, which has been applied in many studies.

The structure of mating systems and description of breeds used in the study will be in this chapter. The statistical models applied and the conditions of their application are also presented. Appropriate statistical models were identified for the comparison of mating systems as well as for separation of the various components of genetic effects. The structure of this system is fairly complex compared to other studies. This was made possible through proper planning and commitment to continuity on the part of the implementors.

Source of Data

A total of 1,180 preweaning records were collected at the Ben Hur beef cattle crossbreeding unit of the Louisiana Agricultural Experiment Station, Baton Rouge, from 1989 to 1994. Baton Rouge, the capital city of the state of Louisiana, is located at latitude 30^{0} 31' N and longitude 91^{0} 08' W, with an elevation of 10.6 m above sea level. The environment is subtropical, and is characterized by annual temperature and humidity ranges of 18 to 26 ^{0}C and 54 to 88 percent, respectively, and an average annual rainfall of 147 cm.

The data were produced in generation five of an ongoing crossbreeding project. This study was initiated in generation one with Angus (A), Brahman (B), Charolais (C) and Hereford (H) as base breeds and were the only breeds used for four generations. In generation five however, Gelbvieh (G) and Simmental (S) were included as terminal sires breeds. Details of progeny composition for generations one to four can be obtained from Tawah (1987), Williams et al. (1991), DeRouen et al. (1992), Habet (1996), and Yilmaz (1996).

Generation-five data were produced through a combination of crossbreeding strategies involving 14 cow lines. Cows from the four straightbred lines (A, B, C, and H) were mated to sire breeds of this group to produce Brahman cross and Angus-Hereford F_1 calves. Three-breed cross calves were produced by mating three lines of F_1 cows (AB, CB, and HB and reciprocals) to the two terminal sire breeds. The two-breed rotational (B21A11, B21C11, B21H11), three-breed rotational (C18B9A5, A18B9H5, C18B9H5) and four-breed rotational (A17B9C4H2) cows were mated to rotation and to terminal sire breeds to produce rotational and rotational-terminal calves, respectively. Rotation sire breeds used in each instance were the breed least represented in the pedigrees of the cows; for example, A18B9H5 cows were mated to H sires. The numbers following the breed codes in the composition of crossbred calves or dams, represent the proportion of that breed in the animal. For example B21A11 designates 21/32 Brahman and 11/32 Angus. Progeny composition and the total number of calves by sire breed and dam breed type are presented in Tables 3.1and 3.2, respectively.

The four breeds used to initiate the study were selected based on their predominance in Louisiana at the time. The Angus *(Bos taurus)* is a British breed of moderate size, known for early maturity, high fertility, and good mothering ability and is represented in most commercial cow-calf operations in Louisiana. Hereford (*Bos taurus*), is another moderate sized British breed which is common in Louisiana, but unlike Angus, tends to have a moderate rate of maturity and low milk production. The Brahman (*Bos indicus*), is the result of an upgrading program in the second quarter of the 20th Century. This upgrading process involved mating native and domestic cows, typical of the Gulf Coast region, to various strains of Zebu males (Sanders, 1980). Interest in the exploitation of Brahman cattle was based on the ability of this breed and its crosses to adapt to the hot, humid conditions of the Gulf Coast region and generally to tolerate cattle pests that were troublesome to other

Table 3.1. Calf breed type by sire breed and dam breed type

	Sire breed					
Dam breed type[a]	A	B	C	G	H	S
<u>Purebred</u>						
A	-	A1B1	-	-	A1H1	-
B	A1B1[b]	-	B1C1	-	B1H1	-
C	-	B1C1	-	-	-	-
H	A1H1	B1H1	-	-	-	-
<u>First-cross</u>						
AB + BA	-	-	-	G2A1B1	-	S2A1B1
BC + CB	-	-	-	G2B1C1	-	S2B1C1
BH + HB	-	-	-	G2B1H1	-	S2B1C1
<u>Rotational-Two-breed</u>						
B21A11	A43B21	-	-	G32B21A11	-	S32B21A11
B21C11	-	-	C43B21	G32B21C11	-	S32B21C11
B21H11	-	-	-	G32B21H11	H43B21	S32B21H11
<u>Three-breed</u>						
A18B9H5	-	-	-	G32A18B9H5	H37A18B9	S32A18B9H5
C18B9A5	A37C18B9	-	-	G32C18B9A5	-	S32C18B9A5
C18B9H5	-	-	-	G32C18B9H5	H37C18B9	S32C18B9H5
<u>Four-breed</u>						
A17B9C4H2	-	-	-	G32A17B9C4H2	H34A17B9C4	S32A17B9C4H2

[a]A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[b]Numbers after breed code = proportion of that breed in the calf or dam. Example B21A11 = 21/32 Brahman and 11/32 Angus.

Table 3.2. Frequency distribution of preweaning data by mating type

Dam breed type[a,b]	Sire breed A	B	C	G	H	S	Dam breed total
A	-	26	-	-	24	-	50
B	36	-	22	-	14	-	72
C	-	28	-	-	-	-	28
H	36	27	-	-	-	-	63
A1B1	-	-	-	63	-	63	126
B1C1	-	-	-	36	-	32	68
B1H1	-	-	-	31	-	45	76
B21A11	47	-	-	16	-	20	83
B21C11	-	-	58	17	-	17	92
B21H11	-	-	-	18	54	25	97
A18B9H5	-	-	-	37	51	26	114
C18B9A5	51	-	-	24	-	19	94
C18B9H5	-	-	-	27	61	35	123
A17B9C4H2	-	-	-	25	42	27	94
Sire breed total	170	81	80	294	246	309	1180

[a]A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.

[b]Numbers following breed codes, within dam breed type, indicate the proportion of that breed in the crossbred dam. For example, B21A11 represents 21/32 Brahman and 11/32 Angus.

breeds (Franke, 1980). The Charolais (*Bos taurus*) is known for superior growth rate and early maturity, and was the first breed from continental Europe to be used extensively in commercial herds in the U.S. Gelbvieh and Simmental cattle (both *Bos taurus*) are also from continental Europe and are early maturing breeds, but the Simmental tends to be larger.

Management of Cattle

Each breeding herd consisted of 20 to 30 females which were randomly assigned according to breed type and age. A 75 d mating season was initiated April 15 of each year. Prior to each breeding season bulls were weighed, dewormed, and fertility tested. The bulls were purchased from Louisiana breeders and were selected on the basis of structural soundness and body size as well as fertility of their dams. Bulls were first used at 2 years of age and kept for only two breeding seasons to maximize the sampling of bulls from each breed.

Calves were born from January 15 to April 1 of each year. and were weighed, dehorned and identified at birth. Male calves were castrated at 5 months of age. Weaning of calves occured at an average age of 190 days during the first week of October. Calves were vaccinated at approximately two months of age and at weaning with a 7-way clostridial vaccine. This was done to provide protection against blackleg, malignant edema, *Clostridium sordeli* infections and enterotoxemia. Replacement heifers were selected at about one year of age. These heifers were managed for first calving at 2 years of age. This was accomplished by a pasture feeding program for average daily gain of at least .57 kg. Pregnancy status was determined in October of each year. Cows were culled for failure to produce a calf in two consecutive years, reproductive problems, or structural unsoundness.

Cows were maintained on pasture throughout the year with the assumption that forages and supplements provided adequate amounts of nutrients to meet NRC requirements for body maintenance and production. Summer pastures consisted of common bermuda (*Cynadon dactylon*) and dallisgrass (*Paspalum dilatatum*); spring pastures contained Louisiana S-1 white clover (*Trifolium repens*); winter pastures featured overseeded ryegrass (*Lolium multiflorum*). During the winter, grazing was supplemented with native hay and fortified cane molasses (32% crude protein).

At the beginning of the breeding season cows were vaccinated with Cattlemaster IV + VL5. This product was to protect against four viral infections, namely infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), parainfluenza-3 (PI-3), and bovine respiratory syncytia (BRS); and reproductive diseases, vibriosis and leptospirosis.

Response Traits

The preweaning traits considered in this study were birth weight (BWT), preweaning average daily gain (ADG), adjusted weaning weight (WWT), and hip height at weaning (WHT). Average daily gain was calculated as actual weaning weight minus birth weight, divided by age of calf at weaning in days. Weaning weight was adjusted to 205 d equivalent according to BIF (1996) recommendations.

The formula used was (((actual weaning weight - actual birth weight)/actual weaning age) x 205) + actual birth weight.

Statistical Analysis for Comparison Among Mating Systems

Preweaning data were analyzed using general linear models (GLM) procedures of SAS (1996). Eight mating systems were coded based on dam breed type and sire breed category (rotational vs terminal). The eight mating systems represented the production of F_1 calves, two-, three-, and four-breed rotational calves, three-breed terminal calves; and two-, three-, and four-breed rotational terminal calves. The first analysis involved the entire data set, then separate analyses were performed for the different mating systems having similar cow line types (straightbred, F_1, two-, three-, and four-breed rotation). Five such analyses were conducted consisting of F1 calves, progeny of two-breed rotational cows by rotational and terminal sires, progeny of three-breed rotational cows by rotational and terminal sires, progeny of four-breed rotational cows mated to rotational and terminal sires, and three-breed terminal calves. The model for the analysis of the combined data for BWT, WWT, ADG, and WHT was:

$$Y_{ijklm} = \mu + YR_i + MSY_j + LN(MSY)_{k:j} + CS_l + b_1G + b_2G^2 + b_3JBD + YR.CS_{il} + MSY.CS_{jl} + E_{ijklm}$$

where,

Y_{ijklm} = observation on the mth calf, born of the lth sex, within the kth line, of the jth mating system during the ith year,

μ = overall mean,

YR_i = effect due to the ith year of birth,

MSY_j = effect due to the jth mating system,

$LN(MSY)_{kj}$ = effect due to the kth cow line within the jth mating system,

CS_l = effect due to the lth sex of calf,

YR.CS = interaction of year and sex of calf,

MSY.CS = interaction of mating system and calf sex,

b_1 and b_2 = partial regression coefficients of y_{ijklm} on the linear and quadratic age of dam in years (G) ,

b_3 = partial regression coefficient of y_{ijklm} on the linear Julian birth date (JBD) and,

E_{ijklm} = random error associated with the measurement on the mth calf born of the lth sex within the kth line of the jth mating system during the ith YR; and assumed to be normally distributed with mean zero and variance σ^2.

Least squares analysis of variance mean squares and significance levels were obtained for each preweaning trait. Least squares means were estimated for relevant predictor variables in each analysis. Comparisons were made between levels of variables using 't' tests of least squares means. In some cases more comparisons were made than the degrees of freedom for the source of variation, contributing to a lower level of significance than indicated.

For the analyses of data by dam line type, similar models were used in each case with necessary modifications according to the mating system. The most complex model included effects of calf sex, cow line, mating type or mating system, mating system x cow line, sire within mating system x cow line, Julian birth date, and linear and quadratic effects of age of cow and of year. Mating type was coded to distinguish between breed combinations within F1and three-breed terminal mating systems, respectively. The effect of mating system was not appropriate in the analyses for F1 and three breed terminal calves since only one mating system was involved in each case. Similarly, line effects were not appropriate for mating systems which included four-breed rotational dams since only one line existed.

Statistical Analysis for Estimation of Genetic Effects

Breed direct and maternal additive and non-additive genetic effects for preweaning traits were partitioned using multiple regression procedures in GLM of SAS (1996). This regression approach has been employed extensively in analyses of economically important traits in cattle (Dillard et al. 1980; Robison et al., 1981; Neville et al., 1984; Wyatt and Franke, 1986; Gallivan et al., 1987; Tawah, 1987; Williams et al., 1991; DeRouen et al.,1992; and Habet, 1996) and in other livestock species (Sellier, 1976; Nitter, 1978; and Baas et al., 1992a,b).

The model used was:

$Y = \mu + fA*IgA + fB*IgB + fC*IgC + fG*IgG + fH*IgH + fS*IgS + fAB*IhAB +$

$fAC*IhAC + fAH*IhAH + fBC*IhBC + fBH*IhBH + fCH*IhCH + f'A*MgA +$

$f'B{*}MgB + f'C{*}MgC + f'H{*}MgH + f'AB{*}MhAB + f'AC{*}MhAC + f'AH{*}MhAH + f'BC{*}MhBC + f'BH{*}MhBH + f'CH{*}MhCH + CS + b_1G + b_2G^2 + b_3JBD + b_4 JBD^2 + error$.

Where,

μ, CS, b_1, b_2, and b_3 are as defined in the model for mating systems, and b_4 is the partial regression coefficient of the dependent variables on the quadratic effect of JBD,

Y = observed preweaning trait (BWT, ADG, WWT or WHT),

Ig and Mg = direct and maternal additive genetic effects, respectively for the breeds indicated.

Ih and Mh = direct and maternal non-additive genetic effects respectively for the breed combinations (AB, AC, AH, BC, BH, CH),

f and f' = proportion of genes in calf or dam from their respective sire and dam components, or proportion of loci with genes from one breed paired with genes from another breed in the calf or dam,

error is assumed to be normally and independently distributed with mean of zero and variance = σ^2.

Assumptions for use of the regression procedure to partition genetic effects include:

1. All genetic effects (direct and maternal, additive and non-additive) were fixed.
2. There was a linear association between breed heterozygosity and heterosis.
3. Linkage and epistatic effects were negligible, therefore dominance effects

were the main source of heterotis, with no correlation between additive and dominance effects.

4. Grand-maternal additive and non-additive effects were insignificant.
5. The proportion of genes contributed by each breed and level of heterozygosity for each breed combination were continuous independent variables. The direct effects refer to influences on the calf and the maternal effects refer to influences of the dam.
6. The direct and maternal additive effects were deviations from the overall least squares mean and therefore sum to zero (IgA + IgB + IgC + IgG + IgH + IgS = MgA + MgB + MgC + MgH = 0).

Because of these linear dependencies, coefficients of IgH and MgH were subtracted, before the analysis, from the direct and maternal additive coefficients, respectively, of the other breeds in the study. This allowed all Ig and Mg effects to be estimated as deviations from the overall mean rather than from an omitted breed. The Estimate statement of SAS (1996) was used to obtain predictions of IgH and MgH. Coefficients used for the estimation of the direct additive and heterotic effects are presented in Tables 3.3 and 3.4, respectively, while the coefficients for the estimation of the maternal additive and heterotic effects are in Table 3.5.

Comparisons of genetic effects among breeds or breed combinations for each preweaning trait were made using the Estimate statement in the GLM procedure of SAS (1996). The comparisons of interest for the direct additive genetic effects were:

Table 3.3. Coefficients for estimation of direct additive genetic effects for preweaning traits of beef cattle

Mating: Sire x dam[a,b]	A	B	C	G	H	S
A x B	1/2	1/2	0	0	0	0
A x H	1/2	0	0	0	1/2	0
B x A	1/2	1/2	0	0	0	0
B x C	0	1/2	1/2	0	0	0
B x H	0	1/2	0	0	1/2	0
C x B	0	1/2	1/2	0	0	0
H x A	1/2	0	0	0	1/2	0
H x B	0	1/2	0	0	1/2	0
G x A1B1	1/4	1/4	0	1/2	0	0
G x C1B1	0	1/4	1/4	1/2	0	0
G x H1B1	0	1/4	0	1/2	1/4	0
S x A1B1	1/4	1/4	0	0	0	1/2
S x C1B1	0	1/4	1/4	0	0	1/2
S x H1B1	0	1/4	0	0	1/4	1/2
A x B21A11	43/64	21/64	0	0	0	0
C x B21C11	0	21/64	43/64	0	0	0
G x B21A11	11/64	21/64	0	1/2	0	0
G x B21C11	0	21/64	11/64	1/2	0	0
G x B21H11	0	21/64	0	1/2	11/64	0
H x B21H11	0	21/64	0	0	43/64	0
S x B21A11	11/64	21/64	0	0	0	1/2
S x B21C11	0	21/64	11/64	0	0	1/2
S x B21H11	0	21/64	0	0	11/64	1/2
A x C18B9A5	37/64	9/64	18/64	0	0	0
G x A18B9H5	18/64	9/64	0	1/2	5/64	0
G x C18B9A5	5/64	9/64	18/64	1/2	0	0
G x C18B9H5	0	9/64	18/64	1/2	5/64	0
H x A18B9H5	18/64	9/64	0	0	37/64	0
H x C18B9H5	0	9/64	18/64	0	37/64	0
S x A18B9H5	18/64	9/64	0	0	5/64	1/2
S x C18B9A5	5/64	9/64	18/64	0	0	1/2
S x C18B9H5	0	9/64	18/64	0	5/64	1/2
G x A17B9C4H2	17/64	9/64	4/64	1/2	2/64	0
H x A17B9C4H2	17/64	9/64	4/64	0	34/64	0
S x A17B9C4H2	17/64	9/64	4/64	0	2/64	1/2

[a]A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[b]Numbers following breed codes for dams indicate the proportion of that breed in the dam. For example B21A11represents 21/32 Angus and 11/32 Brahman.

Table 3.4. Coefficients for estimation of direct heterotic genetic effects for preweaning traits of beef cattle

Mating: Sire x dam[a,b]	AB	AC	AH	BC	BH	CH
A x B	1	0	0	0	0	0
A x H	0	0	1	0	0	0
B x A	1	0	0	0	0	0
B x C	0	0	0	1	0	0
B x H	0	0	0	0	1	0
C x B	0	0	0	1	0	0
H x A	0	0	1	0	0	0
H x B	0	0	0	0	1	0
G x A1B1	0	0	0	0	0	0
G x C1B1	0	0	0	0	0	0
G x H1B1	0	0	0	0	0	0
S x A1B1	0	0	0	0	0	0
S x C1B1	0	0	0	0	0	0
S x H1B1	0	0	0	0	0	0
A x B21A11	21/32	0	0	0	0	0
C x B21C11	0	0	0	21/32	0	0
G x B21A11	0	0	0	0	0	0
G x B21C11	0	0	0	0	0	0
G x B21H11	0	0	0	0	0	0
H x B21H11	0	0	0	0	21/32	0
S x B21A11	0	0	0	0	0	0
S x B21C11	0	0	0	0	0	0
S x B21H11	0	0	0	0	0	0
A x C18B9A5	9/32	18/32	0	0	0	0
G x A18B9H5	0	0	0	0	0	0
G x C18B9A5	0	0	0	0	0	0
G x C18B9H5	0	0	0	0	0	0
H x A18B9H5	0	0	18/32	0	9/32	0
H x ~~A~~C18B9H5	0	0	0	0	9/32	18/32
S x A18B9H5	0	0	0	0	0	0
S x C18B9A5	0	0	0	0	0	0
S x C18B9H5	0	0	0	0	0	0
G x A17B9C4H2	0	0	0	0	0	0
H x A17B9C4H2	0	0	17/32	0	9/32	4/32
S x A17B9C4H2	0	0	0	0	0	0

[a]A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[b]Numbers following breed codes for dams indicate the proportion of that breed in the dam. For example B21A11 represents 21/32 Angus and 11/32 Brahman.

Table 3.5. Coefficients for estimation of maternal additive and heterotic genetic effects for preweaning traits of beef cattle

Mating type[a,b]	Maternal additive				Maternal heterotic					
Sire x dam	A	B	C	H	AB	AC	AH	BC	BH	CH
A x B	0	1	0	0	0	0	0	0	0	0
A x H	0	0	0	1	0	0	0	0	0	0
B x A	1	0	0	0	0	0	0	0	0	0
B x C	0	0	1	0	0	0	0	0	0	0
B x H	0	0	0	1	0	0	0	0	0	0
C x B	0	1	0	0	0	0	0	0	0	0
H x A	1	0	0	0	0	0	0	0	0	0
H x B	0	1	0	0	0	0	0	0	0	0
G x A1B1	1/2	1/2	0	0	1	0	0	0	0	0
G x C1B1	0	1/2	1/2	0	0	0	0	1	0	0
G x H1B1	0	1/2	0	1/2	0	0	0	0	1	0
S x A1B1	1/2	1/2	0	0	1	0	0	0	0	0
S x C1B1	0	1/2	1/2	0	0	0	0	1	0	0
S x H1B1	0	1/2	0	1/2	0	0	0	0	1	0
A x B21A11	11/32	21/32	0	0	11/16	0	0	0	0	0
C x B21C11	0	21/32	11/32	0	0	0	0	11/16	0	0
G x B21A11	11/32	21/32	0	0	11/16	0	0	0	0	0
G x B21C11	0	21/32	11/32	0	0	0	0	11/16	0	0
G x B21H11	0	21/32	0	11/32	0	0	0	0	11/16	0
H x B21H11	0	21/32	0	11/32	0	0	0	0	11/16	0
S x B21A11	11/32	21/32	0	0	11/16	0	0	0	0	0
S x B21C11	0	21/32	11/32	0	0	0	0	11/16	0	0
S x B21H11	0	21/32	0	11/32	0	0	0	0	11/16	0
A x C18B9A5	5/32	9/32	18/32	0	0	5/16	0	9/16	0	0
G x A18B9H5	18/32	9/32	0	5/32	9/16	0	5/16	0	0	0
G x C18B9A5	5/32	9/32	18/32	0	0	5/16	0	9/16	0	0
G x C18B9H5	0	9/32	18/32	5/32	0	0	0	9/16	0	5/16
H x A18B9H5	18/32	9/32	0	5/32	9/16	0	5/16	0	0	0
H x C18B9H5	0	9/32	18/32	5/32	0	0	0	9/16	0	5/16
S x A18B9H5	18/32	9/32	0	5/32	9/16	0	5/16	0	0	0
S x C18B9A5	5/32	9/32	18/32	0	0	5/16	0	9/16	0	0
S x C18B9H5	0	9/32	18/32	5/32	0	0	0	9/16	0	5/16
G x A17B9C4H2	17/32	9/32	4/32	2/32	9/16	4/16	2/16	0	0	0
H x A17B9C4H2	17/32	9/32	4/32	2/32	9/16	4/16	2/16	0	0	0
S x A17B9C4H2	17/32	9/32	4/32	2/32	9/16	4/16	2/16	0	0	0

[a]A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[b]Numbers following each breed code, within dam breed type, indicate the proportion of that breed in the crossbred dam. For example B21A11 represents 21/32 Angus and 11/32 Brahman.

Continental European breed vs non-Continental breeds, rotational sire breeds vs terminal breeds, Brahman vs *Bos taurus* (among rotational breeds), Charolais vs Angus and Hereford, Angus vs Hereford, and Simmental vs Gelbvieh. Comparisons among breeds for maternal additive genetic effects included Brahman vs *Bos taurus* (among rotational breeds), Charolais vs Angus and Hereford, and Angus vs Hereford. Comparisons of heterotic genetic effects among breeds combinations included Brahman vs non-Brahman combinations, Angus-Brahman and Hereford-Brahman vs Charolais-Brahman, Angus-Brahman vs Brahman-Hereford, Angus-Charolais and Charolais-Hereford vs Angus-Hereford, and Angus-Charolais vs Charolais-Hereford.

Chapter IV

Comparison Among Mating Systems

Introduction

Research in animal genetics should include the design of long term breeding experiments that can provide information to livestock producers. In the case of crossbreeding, such information should include options regarding the choice of breeds as well as mating systems that will maximize production efficiency. A producer is usually interested in increasing the mean performance of a herd per breeding female when crossbreeding is implemented.

Tess and Lamb (1992) provided an outline of the concepts and systems of crossbreeding that included considerations of the circumstances under which they are ideally applied. Dickerson (1969) observed that the accurate identification and selection of the ideal crossbreeding system required experimental evaluation of the performance levels achievable by alternative methods.

The information provided in this section includes the statistical analyses comparing eight mating systems involving Angus (A), Brahman (B), Charolais (C), Hereford (H), Gelbvieh (G), and Simmental (S) breeds, as outlined in Chapter 3. Comparisons of results for similar mating systems involving analysis for birth weight (BWT), preweaning average daily gain (ADG), weaning weight (WWT), and hip height at weaning (WHT) are also included.

Least Squares Analysis of Variance

Least squares analysis of variance mean squares and significance levels for preweaning traits, across mating systems, are in Table 4.1. Mating system (MSY), line (LN) within mating system, sex of calf (CS) and year (YR) were significant or highly significant sources of variation for all preweaning traits. The linear and quadratic effects of cow age were highly significant for ADG and WWT, while only the linear effect of cow age was significant for WHT. Regression on Julian birth date (JBD) was highly significant for BWT and WHT. The MSY x CS interaction was significant for BWT ($P < .05$) and YR x CS for BWT ($P < .01$) and WHT ($P < .05$).

There are numerous reports supporting the influence of CS on preweaning traits, particularly BWT, ADG, and WWT (Cartwright et al., 1964; Cundiff et al., 1974b; Crockett et al., 1978; Dillard et al., 1980; Olson et al., 1985; Roberson et al., 1986; Urick et al., 1986; Comerford et al., 1988; Elzo et al., 1990). Crockett et al. (1978) found that mating group, year of birth and age of dam were highly significant sources of variation for BWT and WWT. Ellis et al. (1979) reported that birth year was highly significant for WWT. Similar results were also reported by Dillard et al. (1980), and they also found year of birth to be a highly significant source of variation for BWT and ADG. Olson et al. (1985) reported that the effect of year of birth was highly significant for ADG and WWT was highly significant. Comerford et al. (1988) also found birth year to be a highly significant source of variation for ADG and WWT. Elzo et al. (1990) found variation in BWT and WWT due to birth year

Table 4.1. Least squares analysis of variance mean squares (MS) for preweaning traits over all mating systems

Traits[a]	BWT		ADG		WWT		WHT	
Sources of variation	df	MS (kg^2)	df	MS (kg^2)	df	MS (kg^2)	df	MS (cm^2)
Mating system (MSY)	7	154.9**	7	.250**	7	10,266.2**	7	461.0**
Line:MSY	13	245.4**	13	.134**	13	5,268.5**	13	297.3**
Year (YR)	5	484.3**	5	.418**	5	18,835.3**	5	758.2**
Sex of calf (CS)	1	167.9*	1	.374**	1	18,453.7**	1	533.4**
MSY x CS	7	77.9*	7	.006	7	358.7	7	12.1
YR x CS	5	116.4**	5	.005	5	233.9	5	42.0*
Cow age, L[b]	1	81.6	1	.582**	1	29,636.1**	1	93.0*
Cow age, Q[c]	1	24.5	1	.438**	1	21,693.5**	1	58.2
Julian birth date, L	1	496.4**	1	.007	1	1,449.7	1	2,205.5**
Residual	1,138	30.2	1,045	.012	1,045	593.8	1,027	15.7
R^2 (%)		27.8		44		43.2		51
CV (%)		14.6		10.2		9.6		3.5

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
[b]Linear, [d]Quadratic.
*P < .05
**P < .01

to be highly significant. This is a reflection of variations in forage quality and quantity as well as differences in age of dam over the years.

Significance levels for least squares analysis of variance mean squares are presented in Table 4.2 for each trait within mating systems. These were summarized from least squares analysis of variance means squares presented in the Appendix. Among F_1 calves CS and sire within mating type (MT) influenced all traits. Among three-breed rotational calves CS and LN were significant for all traits. The number of traits with other significant sources of variation, within each cow line type varied from zero to three.

Least Squares Means

Birth Weight. There was a mean birth weight of 37.7 kg across mating systems with the least squares mean for males (38.3 kg) being larger ($P < .05$) than for females (37.2 kg). Least squares means for preweaning traits by MSY are in Table 4.3. The two largest mean birth weight were 39.4 and 39.1 kg and were found for three-breed rotational-terminal and F_1 calves, respectively. Three-breed terminal calves had a mean BWT of 38.2 kg which was similar to that of F_1 and three-breed rotational-terminal calves. The mean BWT of two-breed rotational-terminal, three-breed rotational and four-breed rotational-terminal calves were similar to that of three-breed terminal calves. First-cross (F_1) calves were expected to have a relatively high BWT since they have the potential for 100% heterosis and include B crosses. Least squares means for preweaning traits by line within mating system and sex by

Table 4.2. Significance levels of least squares analysis of variance mean squares for preweaning traits across mating systems

Cow lines	Straightbred				Frist-cross				Rotational cow lines: Two-breed				Rotational cow lines: Three-breed				Rotational cow lines: Four-breed			
Sources	BW[a]	AG	WW	WH	BW	AG	WW	WH	BW	AG	WW	WH	BW	AG	WW	WH	BW	AG	WW	WH
Calf sex	*	**	**	**	ns	**	**	**	*	ns	ns	**	**	**	**	**	ns	ns	ns	ns
Line (LN)	-	-	-	-	-	-	-	-	ns	ns	ns	*	**	**	**	**	-	-	-	-
MT/MSY[b]	ns	**	**	**	*	ns	*	**	ns	**	**	**	ns	ns	ns	**	ns	ns	ns	**
LN x MSY	-	-	-	-	-	-	-	-	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
Sire:MT	**	**	**	**	*	ns	ns	**	-	-	-	-	-	-	-	-	ns	ns	ns	ns
Sire:LN x MSY	-	-	-	-	-	-	-	-	ns	ns	ns	**	ns	**	**	**	-	-	-	-
Cow age, L[c]	**	**	**	ns	ns	**	**	ns	ns	ns	ns	*	ns	**	**	ns	ns	ns	*	ns
Cow age, Q[d]	**	**	**	ns	ns	*	*	ns	ns	ns	ns	*	ns	**	**	ns	ns	*	*	ns
JBD, L	ns	ns	ns	**	*	ns	ns	**	ns	ns	ns	**	ns	ns	ns	**	**	ns	ns	**
Year, L	ns	ns	ns	ns	**	ns	ns	ns	ns	*	*	*	*	ns	ns	ns	ns	*	*	ns
Year, Q	ns	ns	ns	ns	**	ns	ns	ns	ns	*	*	*	*	ns	ns	ns	ns	*	*	ns

[a]BW = birth weight, AG = average daily gain, WW = weaning weight (205 d), WH = weaning height.
[b]Mating type or mating system.
[c]Linear, [d]Quadratic.
ns = P > .05
*P < .05
**P < .01.

Table 4.3. Least squares means and standard errors for preweaning traits due to mating system

Mating systems[1]	BWT[2] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
F_1[3] calves	$39.1 \pm .42^{a}$	$0.99 \pm .009^{a}$	241.2 ± 1.96^{a}	$112.2 \pm .32^{a}$
T x F_1 cows	$38.2 \pm .35^{ac}$	$1.10 \pm .007^{c}$	264.6 ± 1.65^{c}	$115.6 \pm .27^{cd}$
R x Two-breed rotation	$36.4 \pm .44^{a}$	$1.07 \pm .009^{b}$	255.2 ± 2.03^{b}	$114.0 \pm .33^{b}$
T x Two-breed rotation	$37.6 \pm .53^{bc}$	$1.10 \pm .011^{c}$	263.4 ± 2.44^{c}	$116.2 \pm .40^{c}$
R x Three-breed rotation	$37.3 \pm .45^{bc}$	$1.04 \pm .009^{de}$	250.9 ± 2.02^{bd}	$111.8 \pm .33^{a}$
T x Three-breed rotation	$39.4 \pm .45^{a}$	$1.05 \pm .009^{d}$	255.6 ± 2.09^{b}	$114.8 \pm .34^{bd}$
R x Four-breed rotation	$36.7 \pm .86^{bc}$	$1.01 \pm .017^{ac}$	243.7 ± 3.91^{ad}	$109.2 \pm .61^{e}$
T x Four-breed rotation	$37.3 \pm .77^{bc}$	$1.01 \pm .017^{ac}$	244.3 ± 3.75^{ad}	$114.2 \pm .61^{b}$

[1]R = rotational sire breeds (Angus, Brahman, Charolais, or Hereford); T = terminal sire breeds (Gelbvieh and Simmental).
[2]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
[3]F_1 = first-cross calves and dams, respectively.
[a,b,c,d,e] Means in the same column lacking a common superscript differ ($P < .05$).

mating system are presented in Tables 4.4 and 4.5, respectively. These results show mean BWT ranging from 34.5 kg for F_1 calves produced by B dams to 43.7 kg for progeny of B sires and C dams. Low BWT among progeny of B dams are consistent with reports in the literature (Roberson et al., 1986; Sacco et al., 1989; Elzo et al., 1990), as are the relatively high birth weights for calves produced by C dams (Urick et al., 1986).

The two-, three-, and four-breed rotational calves had similar BWT. Urick et al. (1986) and Olson et al. (1993) found that three-breed rotational calves had higher BWT than two-breed rotational calves. Habet (1996) found, for generations one to four of this study, that the highest BWT among rotational calves was for the four-breed combinations. Among rotational-terminal groups, three-breed rotational-terminal calves were heavier ($P < .01$) at birth than two- and four-breed rotational-terminal calves. Within a few mating types birth weight of females tended to be higher than that of males, accounting for the significance of the CS x MT source of variation.

Least squares means for BWT for F_1 and three-breed terminal calves, by mating type and sex, are shown in Table 4.6. Among F_1 calves, AH had the lowest BWT. The mean BWT of F_1 calves were 37.7, 37.5, 40.8, and 38.4 kg for AB, AH, BC and BH breed types, respectively. The mean BWT of BC was higher ($P < .05$) than for AB but not different from BH. The AB and AH combinations included reciprocal matings while BC and BH were produced exclusively by B sires from C

Table 4.4. Least squares means and standard errors for preweaning traits by line within mating system

Sire type[1] x Line of dam[2,3]	BWT[4] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
R x A	38.0 ± .81	0.93 ± .017	227.8 ± 3.74	109.1 ± .63
R x B	34.5 ± .66	1.11 ± .014	262.8 ± 3.20	116.5 ± .52
R x C	43.7 ± 1.05	1.01 ± .022	250.7 ± 4.85	115.1 ± .79
R x H	40.0 ± .71	0.90 ± .015	223.5 ± 3.35	108.1 ± .55
T x A1B1	36.8 ± .51	1.10 ± .010	263 5 ± 2.35	114.5 ± .39
T x B1C1	39.7 ± .67	1.12 ± .014	269.4 ± 3.18	117.6 ± .52
T x B1H1	38.0 ± .61	1.09 ± .013	260.9 ± 2.82	114.7 ± .47
R x B21A11	35.8 ± .81	1.06 ± .016	253.2 ± 3.67	112.2 ± .60
R x B21C11	38.3 ± .73	1.06 ± .015	256.9 ± 3.36	116.4 ± .55
R x B21H11	35.1 ± .75	1.07 ± .015	255.4 ± 3.47	113.3 ± .56
T x B21A11	36.8 ± .93	1.11 ± .019	265.2 ± 4.33	115.7 ± .71
T x B21C11	38.1 ± .94	1.11 ± .019	264.7 ± 4.31	116.3 ± .70
T x B21H11	38.0 ± .86	1.08 ± .017	260.2 ± 3.85	116.5 ± .63
R x A18B9H5	38.3 ± .78	1.04 ± .016	252.6 ± 3.54	112.5 ± .58
R x C18B9A5	36.2 ± .78	1.02 ± .016	245.5 ± 3.52	110.3 ± .58
R x C18B9H5	37.5 ± .72	1.06 ± .014	254.5 ± 3.22	112.6 ± .53
T x A18B9H5	39.6 ± .85	1.08 ± .017	262.2 ± 3.83	116.0 ± .62
T x C18B9A5	37.6 ± .71	1.01 ± .014	244.7 ± 3.23	112.9 ± .52
T x A18B9H5	40.9 ± .71	1.07 ± .014	259.8 ± 3.46	115.4 ± .56
R x A17B9C4H2	37.6 ± .86	1.01 ± .017	243.7 ± 3.91	109.2 ± .66
T x A17B9C4H2	37.3 ± .77	1.01 ± .017	244.3 ± 3.75	114.2 ± .61

[1]R = rotational sire breeds (A, B, C, or H), T = terminal sire breeds (G and S), below.
[2]A = Angus, B = Brahman, C = Charolais, H = Hereford, G = Gelbvieh, S = Simmental.
[3]Numbers = breed proportions; example, B21A11 = 21/32 Brahman and 11/32 Angus.
[4]BWT = birth weight, ADG = average daily gain, WWT/WHT = weaning weight/height.

Table 4.5. Least squares means for preweaning traits by sex of calf x mating system

	BWT[2] (kg)		ADG (kg)		WWT (kg)		WHT (cm)	
Mating system	Male	Female	Male	Female	Male	Female	Male	Female
Sire type[1] x Dam type								
R x Straightbred	40.5	37.7	1.01	0.96	248.1	234.2	113.5	110.9
T x First-cross	38.8	37.6	1.14	1.07	272.6	256.7	116.2	115.0
R x Two-breed rotation	35.7	37.2	1.08	1.05	258.3	252.0	114.6	113.3
T x Two-breed rotation	37.4	37.9	1.13	1.07	268.8	257.9	117.1	115.2
R x Three-breed rotation	38.5	36.2	1.07	1.02	256.9	244.8	112.5	111.1
T x Three-breed rotation	40.0	38.6	1.08	1.03	261.5	249.6	115.6	113.9
R x Four-breed rotation	37.3	36.0	1.04	0.99	249.1	238.4	110.2	108.2
T x Four-breed rotation	37.9	36.7	1.02	0.99	248.0	240.5	115.8	112.5
Average standard error	.76		.012		3.49		.585	

[1]R = rotational sire breeds (Angus, Brahman, Charolais, or Hereford), T = terminal sire breeds (Gelbvieh and Simmental).
[2]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (adjusted 205 d), WHT = weaning height.

Table 4.6. Least squares means (LSM) and standard errors (SE) for birth weight[1] (kg), by mating type and sex of calf, among first-cross (F_1) and three-breed terminal calves

First-cross calves			Three-breed terminal calves		
	LSM	SE		LSM	SE
Mating type[1]			Mating type[1,2]		
AB	37.7[a]	0.86	T x AB	37.6[a]	0.79
AH	37.5[a]	0.86	T x BC	40.3[b]	0.87
BC	40.8[b]	1.20	T x BH	38.1[ab]	0.84
BH	38.4[ab]	1.00			
Sex of calf			Sex of calf		
Male	39.7*	0.68	Male	39.4	0.63
Female	37.5	0.70	Female	37.9	0.69

[1]AB = Angus x Brahman, AH = Angus x Hereford, BC = Brahman x Charolais, BH = Brahman x Hereford. Describes first-cross calves, as well as first-cross dams of three-breed terminal calves. Also includes reciprocal crosses.
[2]T = Terminal sire breeds, Gelbvieh and Simmental. Sires from both breeds were mated to first-cross dams of each type to produce three-breed terminal calves.
[a,b]Means within columns of a category, lacking a common superscript differ, $P < .05$.
*$P < .05$, male vs female within calf groups.

and H dams, respectively. Therefore, the highest BWT among this group was for calves of C dams which is not surprising, as discussed earlier. In the case of AB the combination of B sired calves with progeny of B dams may account for the relatively high BWT of this group compared with the 34.5 kg reported earlier for progeny of B dams. Males were 2.2 kg heavier ($P < .05$) at birth than female calves in this group.

Among three-breed terminal calves progeny of BC dams were heavier ($P < .01$) at birth than calves from AB dams, but were similar to calves of BH dams. However, BWT of progeny from AB and BH dams were similar.

Least squares means for BWT by MSY and CS are in Table 4.7, while LN and LN x MSY are in Table 4.8, for rotational dam groups. Throughout the discussion two-breed rotational lines B21A11, B21C11, and B21H11will be represented as AB, BC, and BH, respectively. Similarly, the three-breed rotational lines A18B9H5, C18B9A5, and C18B9H5 will be represented by ABH, CBA, and CBH, respectively. Among progeny of two-breed rotational dams, no differences in BWT were found among calves from AB, BC, or BH cow lines overall, nor between calves from these cow lines within each of the two mating systems (rotational and terminal). Additionally, there were no significant differences between rotational vs terminal calves from the two-breed rotational dams.

The least squares means for BWT of calves from two-breed rotational dams were 36.1, 37.9 and 36.2 kg for AB, BC, and BH rotations, respectively. Habet (1996) reported that CB rotation calves had larger ($P < .05$) BWT than AB and HB

Table 4.7. Least squares means (LSM) and standard errors (SE) for birth weight (kg), by mating system and sex of calf, among progeny of rotational dams

Dam breed type	Two-breed rotational		Three-breed rotational		Four-breed rotational	
	LSM	SE	LSM	SE	LSM	SE
Mating system[1]						
Rotational	36.3	0.57	37.5	0.58	37.1	0.95
Terminal	37.1	0.59	38.5	0.55	37.0	0.88
Sex of calf						
Male	35.9	0.59	39.1**	0.55	37.6	0.98
Female	37.6*	0.57	37.0	0.56	36.5	0.89

[1]Rotational sire breeds (Angus, Brahman, Charolais or Hereford) x rotational dams vs terminal sire breeds (Gelbvieh and Simmental) x rotational dams.
*P < .05, ** P < .01, male vs female within dam breed type.

Table 4.8. Least squares means and standard errors for birth weight by line and line x mating system among progeny, within two- and three-breed rotational dams

Lines[1,2,3]	Line means (kg)	Mating system[4] means (kg) Rotational	Terminal
Two-breed			
B21A11	36.1 ± .73	36.1 ± .99[ab]	36.0 ± 1.07[ab]
B21C11	37.9 ± .74	37.5 ± 1.06[ab]	38.2 ± 1.03[b]
B21H11	36.2 ± .65	35.2 ± .92[a]	37.2 ± .96[ab]
Three-breed			
A18B9H5	36.5 ± .64[a]	36.1 ± .94[a]	36.8 ± .86[a]
C18B9A5	38.4 ± .78[ab]	38.7 ± 1.11[ab]	38.1 ± 1.06[ab]
C18B9H5	39.2 ± .62[b]	37.7 ± .91[a]	40.7 ± .87[b]

[1]Line is the breed type of dams.
[2]Breed codes: A = Angus, B = Brahman, C = Charolais, H = Hereford.
[3]Numbers following breed codes, within each line of dam, indicate the proportion of that breed represented in the dam. For example, C18B9A5 designates 18/32 Charolais, 9/32 Brahman, and 5/32 Angus.
[4]Progeny of rotational sire breeds (A, B, C, or H, above) or of terminal sire breeds Gelbvieh and Simmental.
[a,b]Means within the column of lines or across the two columns of line x mating system, for each rotational dam group, lacking a common superscript differ, $P < .05$.

in generations one, two, and three; and that HB rotation calves had larger ($P < .05$) BWT than AB rotational calves in generation one.

Among three-breed rotational dams, progeny of CBH dams were heavier ($P < .01$) at birth than progeny of ABH dams, while BWT of calves from ABH and CBA dams were similar. No differences in BWT were found within rotational progeny of the three-breed rotational dams. However, terminal calves produced by CBH dams were heavier at birth than terminal progeny of ABH dams but were similar in weight to the terminal calves from CBA dams. Additionally, terminal progeny from CBH dams had higher BWT than rotational progeny from these dams. The means for rotational and terminal calves from ABH, CBA and CBH dams, respectively, were 36.1 and 36.8 kg, 38.7 and 38.1 kg, 37.7 and 40.7 kg. Habet (1996) found that BCH rotational calves were larger ($P < .01$) at birth than ABC and ABH rotational calves during the first three generations of the study. Similar BWT of 37.1 and 37.0 kg were found for rotational and terminal calves, respectively from four-breed rotational dams.

Female calves were heavier ($P < .05$) at birth than males within two-breed rotational dams, but there was no difference in BWT between males and females of four-breed rotational dams. Among three-breed rotational dams however, the more common pattern was observed, male calves had larger ($P < .01$) BWT than females.

Preweaning Average Daily Gain. Calves in generation five gained at an average rate of 1.05 kg/d. Male calves gained at a higher ($P < .01$) rate than females (1.07 vs 1.02 kg). Two-breed rotational-terminal and three-breed terminal calves had

ADG of 1.10 kg/d. Among the other mating systems, ADG in descending order of magnitude were 1.07, 1.05, 1.04, 1.01. 1.01, and 0.99 kg/d for two-breed rotational, three-breed rotational-terminal, three-breed rotational, four-breed rotational, four-breed rotational-terminal, and F_1 calves, respectively (Table 4.3). Turner and McDonald (1969) reported that three-breed calves gained .04 kg/d more than backcross calves. Roberson et al. (1986) found that among Brahman, Hereford, and Brahman x Hereford crossbred cattle, calves from F_1 dams had larger preweaning gains than calves of other breed types. Among rotational calves, ADG of three- and four-breed combinations were similar and lower ($P < .05$ and $P < .01$, respectively) than ADG of two-breed rotational calves. Among rotational-terminal calves, the ADG of two-breed combinations was higher ($P < .01$) than three-breed rotations which was in turn, higher ($P < .05$) than the four-breed combination. Urick et al. (1986) showed that three-breed rotational calves exceeded ($P < .01$) two-breed rotational calves for ADG. For the generation one to four data, Habet (1996) found that ADG of four-breed rotational calves was larger than that for two-breed rotational calves but was not different from ADG of three-breed rotational calves.

Least squares means for ADG of F_1 and three-breed terminal calves are presented in Table 4.9. Among F1 calves the ADG of all B-cross calves were similar and greater ($P < .05$) than the ADG for AH calves. Some of these calves were produced by B dams, and benefitted from a superior maternal environment. Other researchers have reported high ADG means for B-cross calves due to the B maternal

Table 4.9. Least squares means (LSM) and standard errors (SE) for average daily gain (kg/d), by mating type and sex of calf, among first-cross (F_1) and three-breed terminal calves

First-cross calves	LSM	SE	Three-breed terminal calves	LSM	SE
Mating type[1]			Mating type[1,2]		
AB	1.06[a]	.018	T x AB	1.10[ab]	.014
AH	0.91[b]	.019	T x BC	1.13[b]	.016
BC	1.01[a]	.026	T x BH	1.08[a]	.015
BH	1.01[a]	.023			
Sex of calf			Sex of calf		
Male	1.03**	.015	Male	1.13**	.012
Female	0.96	.015	Female	1.08	.013

[1]AB = Angus x Brahman, AH = Angus x Hereford, BC = Brahman x Charolais, BH = Brahman x Hereford. Describes first-cross calves, as well as first-cross dams of three-breed terminal calves. Also includes reciprocal crosses.
[2]T = Terminal sire breeds, Gelbvieh and Simmental. Sires from both breeds were mated to first-cross dams of each type to produce three-breed terminal calves.
[a,b]Means within columns of a category, lacking a common superscript differ, $P < .05$.
**$P < .01$, male vs female within calf groups.

environment (Peacock et al. 1978, 1978; Wyatt and Franke, 1986). Average daily gain for male and female calves were 1.03 and 0.96 kg, respectively ($P < .01$).

Least square means of 1.10, 1.13 and 1.08 kg for ADG were observed for three-breed terminal calves produced by AB, BC, and BH dams, respectively. The ADG for calves from BC dams was significantly higher than ADG of calves from BH dams, but similar to ADG of calves from AB dams. Belcher and Frahm (1979) showed that calves from BA dams gained .06 kg/d more than calves from BH dams. Males within the three-breed terminal group gained .05 kg more ($P < .01$) per day than the 1.08 kg ADG of females.

Least squares means for ADG of rotational dam groups by sex and mating system are presented in Table 4.10, and by line and line within mating system in Table 4.11. The ADG means for rotational and terminal calves from two-breed rotational dams were 1.06 and 1.12 kg/d, respectively. The .06 kg/d greater ($P < .01$) gain of two-breed rotational-terminal calves was largely due to the difference in ADG of .07 kg/d ($P < .05$) between terminal and rotational calves of BA dams. Differences in ADG between terminal vs rotational calves from BC and from BH dams were not significant. The overall mean ADG for calves from two-breed rotational dams were1.10, 1.10, and 1.09 kg/d for BA, BC and BH dams, respectively. Marshall et al. (1990) found differences in ADG of two-breed rotational calves due to cow line. They reported that within AH rotations, ADG of calves fron AHA dams exceeded the ADG of calves from HAH dams by .03 kg/d. Additionally, that calves

Table 4.10. Least squares means (LSM) and standard errors (SE) for average daily gain (kg/d), by mating system and sex of calf, among progeny of rotational dams

Dam breed type	Two-breed rotational		Three-breed rotational		Four-breed rotational	
	LSM	SE	LSM	SE	LSM	SE
Mating system[1]						
Rotational	1.06	.013	1.05	.011	1.02	.024
Terminal	1.12**	.013	1.05	.010	1.00	.024
Sex of calf						
Male	1.11	.012	1.08**	.010	1.04	.027
Female	1.08	.013	1.01	.010	0.98	.022

[1]Rotational sire breeds (Angus, Brahman, Charolais or Hereford) x rotational dams vs terminal sire breeds (Gelbvieh and Simmental) x rotational dams.
** P < .01, rotational vs terminal or male vs female within dam breed type.

Table 4.11. Least squares means and standard errors for average daily gain by line and line x mating system among progeny, within two- and three-breed rotational dams

		Mating system[4] means (kg/d)	
Lines[1,2,3]	Line means (kg/d)	Rotational	Terminal
Two-breed			
B21A11	1.10 ± .016[a]	1.06 ± .022[ac]	1.13 ± .023[b]
B21C11	1.10 ± .016[a]	1.07 ± .023[abc]	1.13 ± .022[b]
B21H11	1.09 ± .014[a]	1.06 ± .020[c]	1.11 ± .021[abc]
Three-breed			
A18B9H5	1.01 ± .014[a]	1.03 ± .020[ab]	0.99 ± .016[b]
C18B9A5	1.05 ± .012[b]	1.04 ± .018[ac]	1.07 ± .019[ac]
C18B9H5	1.07 ± .012[a]	1.07 ± .016[ac]	1.08 ± .016[c]

[1]Line is the breed type of dams.
[2]Breed codes: A = Angus, B = Brahman, C = Charolais, H = Hereford.
[3]Numbers following breed codes, within each line of dam, indicate to the proportion of that breed represented in the dam. For example, C18B9A5 designates 18/32 Charolais, 9/32 Brahman, and 5/32 Angus.
[4]Progeny of rotational sire breeds (A, B, C, or H, above) or of terminal sire breeds, Gelbvieh and Simmental.
[a,b]Means within the column of lines or across the two columns of line x mating system, for each rotational dam group, lacking a common superscript differ, $P < .05$.

from SHS dams gained .04 kg/d more than calves from HSH dams. Habet (1996) found that among two-breed rotations, in generations one through four, CB calves had larger ($P < .05$) ADG than AB and HB calves. The CB exceeded the average of AB and HB in ADG by .067 kg/d, while there was no difference in ADG for AB and HB rotational combinations.

Within calves from three-breed rotational dam groups, progeny of CBA and CBH dams gained .04 ($P < .05$) and .06 ($P < .01$) kg/d more, respectively than progeny of ABH dams. Differences in ADG between rotational and terminal calves were not significant. However the general trend was toward higher ADG for calves of terminal sire breeds. The ADG for rotational calves in this group were 1.03, 1.04, and 1.07 kg for ABH, CBA and CBH rotations, while the corresponding values for terminal calves were 0.99, 1.07, and 1.08 kg, respectively. Within the rotational calves of three-breed rotational dams, ADG means were similar. Among three-breed rotational-terminal calves, progeny of CBA and CBH dams had similar ADG which were larger ($P < .01$) than ADG for rotational-terminal calves from ABH dams. Urick et al. (1986) reported no significant difference in ADG between H x HAC calves and A x HAC calves. Habet (1996) reported that within three-breed rotations, ABC and BCH calves had similar ADG that were larger ($P < .01$) than the ADG of ABH calves.

The ADG of rotational and terminal calves from four-breed rotational dams were similar, 1.01 kg in both instances. Habet (1996) reported the ADG for four-breed rotational calves as .881, .849, .900, and .949 kg/d for generations one through four, respectively. No difference was found in ADG between male and female calves within two- and four-breed rotational dam groups. However, male progeny from three-breed rotational dams had higher ADG than contemporary female progeny.

Weaning Weight. The average 205 d WWT for all calves was 255.1 kg. Least squares mean WWT for males (257.9 kg) was 11.2 kg higher ($P < .01$) than that of females. Three-breed terminal calves (264.6 kg) and two-breed rotational- terminal calves (263.4 kg) had similar weaning weights which were larger ($P < .05$ or $P < .01$) than WWT of calves from all other mating systems. The lowest WWT was for F_1 calves though it was not significantly different from the weaning weight of calves of the two mating systems involving four-breed rotational dams (Table 4.3). Freedman et al. (1982), Cundiff et al. (1974b), and Frahm and Marshall (1985) reported higher WWT for three-breed cross calves, than for other calves in their studies.

Among rotational calves, WWT for the two-breed combinations were higher ($P < .01$) than for the four-breed combinations, while WWT for three-breed combinations were similar to both the two- and four-breed groups. These findings deviated from the general trend in the literature. Thrift et al. (1986) using partial data from generation three of this study, reported that three-breed rotational calves were heavier ($P < .01$) at weaning than two-breed rotational calves. Additionally, Urick et al. (1986) compared two- and three-breed rotational systems involving A, C, and H crosses. They also reported higher WWT for three-breed rotational calves over that of two-breed rotational calves. Habet (1996) reported that four-breed rotational calves weighed 5.7 kg ($P < .01$) and 2.7 kg ($P < .05$) more than two- and three-breed rotational calves, respectively, and that three-breed rotational calves had larger WWT ($P < .01$) than two-breed rotational calves. Among rotational-terminal calves, progeny of two-breed rotational dams were heavier ($P < .05$) than calves from three-breed rotational dams, which were in turn heavier ($P < .01$) than calves from four-breed rotational dams at weaning (Table 4.3).

Least squares means for WWT by mating type and sex among F_1 and three-breed terminal calves are presented in Table 4.12. Among F_1 calves, Brahman cross progeny had similar WWT that were at least 22 kg larger than that of AH calves. Male calves were 16.9 kg heavier ($P < .01$) than females. The means for AB, AH, BC, and BH calves were 256.7, 222.8, 247.4, and 245.4 kg, respectively. Crockett et al. (1978) also reported higher WWT for B cross calves than for AH calves.

Among three-breed terminal calves, progeny of BC dams had larger ($P < .01$) WWT (273.0 kg) than progeny of AB (262.8 kg) and BH (260.2 kg) dams, which were similar. Belcher and Frahm (1979) reported that progeny of BA dams weaned 11 kg heavier ($P < .05$) than progeny of BH dams. The WWT of three-breed terminal male calves exceeded the WWT of female calves by 11.8 kg ($P < .01$).

Least squares means by sex and mating type for rotational dam groups are presented in Table 4.13 and for line and line x mating type in Table 4.14. Among two-breed rotational dams terminal calves had 13.1 kg larger ($P < .01$) WWT than

Table 4.12. Least squares means (LSM) and standard errors (SE) for weaning weight[1] (kg), by mating type and sex of calf, among first-cross (F_1) and three-breed terminal calves

First-cross calves	LSM	SE	Three-breed terminal calves	LSM	SE
Mating type[2]			Mating type[2,3]		
AB	256.7[a]	4.15	T x AB	262.8[a]	3.24
AH	222.8[b]	4.31	T x BC	273.0[b]	3.73
BC	247.4[a]	5.88	T x BH	260.2[a]	3.41
BH	245.4[a]	5.16			
Sex of calf			Sex of calf		
Male	251.5**	3.38	Male	271.2**	2.63
Female	234.6	3.52	Female	259.5	2.91

[1]Adjusted to 205 d equivqlent.
[2]AB = Angus x Brahman, AH = Angus x Hereford, BC = Brahman x Charolais, BH = Brahman x Hereford. Describes first-cross calves, as well as first-cross dams of three-breed terminal calves. Also includes reciprocal crosses.
[3]T = Terminal sire breeds, Gelbvieh and Simmental. Sires from both breeds were mated to first-cross dams of each type to produce three-breed terminal calves.
[a,b]Means within columns of a category, lacking a common superscript differ, $P < .05$.
**$P < .01$, male vs female within calf groups.

Table 4.13. Least squares means (LSM) and standard errors (SE) for weaning weight[1] (kg), by mating system and sex of calf, among progeny of rotational dams

Dam breed type	Two-breed rotational		Three-breed rotational		Four-breed rotational	
	LSM	SE	LSM	SE	LSM	SE
Mating system[2]						
Rotational	254.6	2.77	251.8	2.38	247.2	5.10
Terminal	267.7**	2.82	252.7	2.29	241.8	4.94
Sex of calf						
Male	262.8	2.84	259.9**	2.35	250.4	5.74
Female	259.6	2.77	244.6	2.37	238.6	4.45

[1]Adjusted to 205 d equivalent.
[2]Rotational sire breeds (Angus, Brahman, Charolais or Hereford) x rotational dams vs terminal sire breeds (Gelbvieh and Simmental) x rotational dams.
** $P < .01$, rotational vs terminal or male vs female within dam breed type.

Table 4.14. Least squares means and standard errors for weaning weight[1] by line and line x mating system among progeny, within two- and three-breed rotational dams

		Mating system[5] means (kg)	
Lines[2,3,5]	Line means (kg)	Rotational	Terminal
Two-breed			
B21A11	260.9 ± 3.45[a]	253.1 ± 4.76[a]	268.6 ± 5.16[b]
B21C11	263.1 ± 3.54[a]	257.2 ± 5.12[abc]	269.0 ± 4.85[b]
B21H11	259.6 ± 3.10[a]	253.6 ± 4.44[ac]	265.5 ± 4.51[abc]
Three-breed			
A18B9H5	242.2 ± 2.65[a]	247.2 ± 4.01[a]	239.2 ± 3.58[b]
C18B9A5	254.6 ± 3.12[b]	252.1 ± 4.52[ac]	257.1 ± 4.30[ac]
C18B9H5	259.8 ± 2.60[b]	256.0 ± 3.71[ac]	261.8 ± 3.71[c]

[1]Adjuated to 205 d equivalent.
[2]Line is the breed type of dams.
[3]Breed codes: A = Angus, B = Brahman, C = Charolais, H = Hereford.
[4]Numbers following breed codes, within each line of dam, indicate the proportion of that breed represented in the dam. For example, C18B9A5 designates 18/32 Charolais, 9/32 Brahman, and 5/32 Angus.
[5]Progeny of rotational sire breeds (A, B, C, or H, above) or of terminal sire breeds Gelbvieh and Simmental.
[a,b,c]Means within the column of lines or across the two columns of line x mating system, for each rotational dam group, lacking a common superscript differ, $P < .05$.

rotational calves, the respective means being 267.7 and 254.6 kg. Weaning weight means were similar for calves from BA, BC, and BH two-breed rotational dams. However, line x mating system effects showed that terminal calves from BA dams had 15.5 kg larger (P < .05) WWT than rotational calves of these dams. No differences in WWT between rotational and terminal calves from BC and BH rotational dams were noted. For generation one to four, Habet (1996) showed that among two-breed rotations, CB calves were the heaviest (P < .01) at weaning within each generation. Additionally, he found that AB and HB calves had similar WWT in generations two, three, and four.

Among three-breed rotational dams, CBA and CBH produced calves with similar WWT that were superior (P < .01) to that of progeny of ABH dams. Among three-breed rotational-terminal calves, progeny of CBA and CBH dams had similar WWT which were larger (P < .01) than WWT of rotational-terminal calves produced by ABH dams. However, no differences were found for rotational vs rotational-terminal calves within three-breed combinations. Habet (1996) also found that WWT means for ABC and BCH were larger (P < .01) than for ABH in the first and second generations. BCH had larger (P < .01) WWT than ABC in the first generation and they were similar in the second generation. He observed no significant differences in WWT between ABC, ABH and BCH rotational calves in generation four.

The WWT of rotational and terminal calves from four-breed rotational dams were similar, the means being 247.2 and 241.8 kg, respectively. Mean WWT of

212.1, 210.5, 223.5, and 226.5 kg for generations one to four, respectively were reported by Habet (1996) for four-breed rotational calves. Male calves from three-breed rotational dams were 15.3 kg heavier ($P < .01$) at weaning than female calves, but for calves from two- and four-breed rotational dams. no differences in WWT, between the sexes were observed.

Hip Height. The mean WHT across mating systems was 113.9 cm. Male calves (114.4 cm) were higher ($P < .01$) than female calves (112.5 cm). Two-breed rotational-terminal and three-breed terminal calves had the largest WHT of 116.2 and 115.6 cm, respectively (Table 4.3). The WHT of four-breed rotational calves was lower than that of calves from all other mating systems. There were significant differences in WHT between two-, three-, and four-breed rotational calves. the respective means being 114.0, 111.8, and 109.2 cm, respectively. The WHT of three-breed rotational-terminal calves was greater ($P <.05$) than four-breed rotational calves and both lower ($P < .01$) than the WHT of two-breed rotational-terminal calves. Among rotational cows two-breed combinations had the highest percentage of B breeding. McCarter et al. (1991) reported that WHT increased in calves as the proportion of B breeding increased. The WHT of F_1 calves was similar to that of three-breed rotational calves and lower than that of calves in all other mating systems except for four-breed rotational calves.

Least squares means for WHT by MT and CS are presented in Table 4.15 for F_1 and three-breed terminal calves. Among F_1 calves, the WHT of AH combination

Table 4.15. Least squares means (LSM) and standard errors (SE) for weaning height (cm), by mating type and sex of calf, among first-cross (F_1) and three-breed terminal calves

First-cross calves			Three-breed terminal calves		
	LSM	SE		LSM	SE
Mating type[1]			Mating type[1,2]		
AB	114.4[bc]	0.68	T x AB	113.7[a]	0.53
AH	106.9[a]	0.71	T x BC	117.7[b]	0.61
BC	116.5[b]	0.98	T x BH	114.7[a]	0.56
BH	112.4[c]	0.85			
Sex of calf			Sex of calf		
Male	113.7**	0.57	Male	116.2**	0.43
Female	111.4	0.58	Female	114.5	0.48

[1]AB = Angus x Brahman, AH = Angus x Hereford, BC = Brahman x Charolais, BH = Brahman x Hereford. Describes first-cross calves, as well as first-cross dams of three-breed terminal calves. Also includes reciprocal crosses.
[2]T = Terminal sire breeds, Gelbvieh and Simmental. Sires from both breeds were mated to first-cross dams of each type to produce three-breed terminal calves.
[a,b]Means within columns of a category, lacking a common superscript differ, P < .05.
**P < .01, male vs female within calf groups.

(106.9 cm) was lower ($P < .01$) than that of the B-cross calves (AB, BC and BH). The BC F_1 calves were taller ($P < .01$) than BH calves, but were similar in height to AB calves at weaning. Males were 2.3 cm taller ($P < .01$) than females at weaning.

Within three-breed terminal calves, progeny of BC dams were taller ($P < .01$) than progeny of AB and BH dams which were similar. The mean WHT of calves from AB, BC and BH dams were 113.7, 117.7, and 114.7 cm, respectively.

Tables 4.16 and 4.17 contain WHT least squares means by sex and mating system and by line and line x mating system, respectively, for progeny of rotational dams. The WHT means of calves from BA, BC and BH rotational dams were 113.9, 115.9 and 114.6 cm, respectively. The progeny of BC rotational dams were taller ($P < .01$) than calves from BA and similar to calves from BH rotational dams. The WHT of calves from BA and BH rotational dams also did not differ. A highly significant difference in WHT occurred between rotational and rotational-terminal calves of two-breed rotational dams. The means were 113.3 and 116.2 cm, respectively. This difference in WHT was evident between rotational vs rotational-terminal calves of BA and BH rotational dams, while for BC rotational dams difference in WHT between rotational vs rotational-terminal calves was not significant. Additionally, among rotational-terminal calves from two-breed rotational dams, WHT means were similar. However, among rotational calves, progeny of BC rotational dams were taller ($P < .01$) than progeny of BA and BH rotational, which were similar in WHT.

Table 4.16. Least squares means (LSM) and standard errors (SE) for weaning height (cm), by mating system and sex of calf, among progeny of rotational dams

Dam breed type	Two-breed rotational		Three-breed rotational		Four-breed rotational	
	LSM	SE	LSM	SE	LSM	SE
Mating system[1]						
Rotational	113.3	.411	111.9	.398	108.9	1.05
Terminal	116.2**	.416	114.5**	.381	113.6**	1.01
Sex of calf						
Male	115.6**	.420	114.0**	.393	111.8	1.16
Female	113.9	.411	112.3	.399	110.7	0.93

[1]Rotational sire breeds (Angus, Brahman, Charolais or Hereford) x rotational dams vs terminal sire breeds (Gelbvieh and Simmental) x rotational dams.
** P < .01, rotational vs terminal or male vs female within dam breed type.

Table 4.17. Least squares means and standard errors for weaning height by line and line x mating system among progeny, within two- and three-breed rotational dams

Lines[1,2,3]	Line means (cm)	Mating system[4] means (cm)	
		Rotational	Terminal
Two-breed			
B21A11	113.9 ± .517[a]	112.1 ± .706[a]	115.7 ± .761[b]
B21C11	115.9 ± .523[b]	115.4 ± .756[b]	116.4 ± .716[b]
B21H11	114.6 ± .459[ab]	112.4 ± .657[a]	116.7 ± .666[b]
Three-breed			
A18B9H5	111.5 ± .520[a]	110.4 ± .671[a]	112.6 ± .598[c]
C18B9A5	113.8 ± .444[b]	112.8 ± .754[c]	114.9 ± .716[b]
C18B9H5	114.2 ± .434[b]	112.5 ± .621[c]	115.9 ± .619[b]

[1]Line is the breed type of dams.
[2]Breed codes: A = Angus, B = Brahman, C = Charolais, H = Hereford.
[3]Numbers following breed codes, within each line of dam, indicate the proportion of that breed represented in the dam. For example, C18B9A5 designates 18/32 Charolais, 9/32 Brahman, and 5/32 Angus.
[4]Progeny of rotational sire breeds (A, B, C or H above) or of terminal sire breeds Gelbvieh and Simmental.
[a,b,c]Means within the column of lines or across the two columns of line x mating system, for each rotational dam group, lacking a common superscript differ, $P < .05$.

Among three-breed rotational dams, progeny of CBA and CBH rotational dams were similar in WHT and taller ($P < .01$) than calves from ABH rotational dams. Rotational-terminal calves were taller ($P < .05$) than rotational calves. The least squares means were 112.6 vs 110.4; 114.9 vs 112.8, and 115.9 vs 112.5 for three-breed rotational-terminal vs rotational calves of ABH, CBA, and CBH rotational dams, respectively. Within rotational as well as rotational-terminal calves, progeny of CBA and CBH rotational dams were similar in WHT and taller ($P < .05$) than calves from ABH rotational dams.

Terminal calves from four-breed rotational dams had WHT of 113.6 cm, while rotational calves had 108.9 cm ($P < .01$). Male calves were taller ($P < .01$) than female calves among progeny of two- and three-breed rotational dams.

Summary

Mating system, line within mating system and sex of calf were highly significant sources of variation for all preweaning traits. Linear regression on Julian birth date was highly significant for BWT and WHT. Three-breed rotational terminal calves and F1 calves had the largest BWT means while two-breed rotational-terminal and three-breed terminal calves had the largest ADG, WWT and WHT. The WHT of three-breed rotational-terminal calves was similar to that three-breed terminal but lower ($P < .01$) than that of two breed rotational calves.

Among rotational calves, two-, three-, and four-breed combinations had similar BWT. Two-breed rotation means were larger than three-breed rotation means, which were in turn larger than four-breed rotation means for ADG and WHT. Two- and three-breed rotational calves had similar WWT. The WWT of four-breed rotational calves was lower ($P < .01$) than that of two-breed rotational calves and similar to three-breed rotational calves. Among the rotational-terminal calves, progeny of three-breed rotational dams had larger BWT than two- and four-breed rotational-terminal calves. Two-breed rotational-terminal calves had the largest ADG, WWT and WHT.

Among F_1 calves, B cross calves had larger means for preweaning traits than AH calves except for BWT; in which AB and BH calves were similar to AH calves, while BC calves were larger than all three of these. Among three-breed terminal calves, progeny of BC dams ranked higher than progeny of BH dams for ADG, WWT and WHT, and higher than progeny of AB dams for BWT, WWT and WHT. Terminal calves from two-breed rotational dams exceeded the performance of rotational calves from these dams in all traits, except for BWT. Among rotational as well as terminal calves from two-breed rotational dams, no significant differences were found between the means of different cow lines for BWT, ADG, and WWT. However, BC rotational calves were taller than BA and BH rotational calves at weaning. Among progeny of three-breed rotational dams, there was no difference between rotational vs terminal calves for BWT, ADG, and WWT, but WHT was greater ($P < .01$) for the terminal calves.

Within dam lines of three-breed rotational calves, progeny of CBA and CBH dams had similar means for ADG, WWT and WHT, that were larger ($P < .05$) than the respective means for calves from ABH dams. Terminal calves from four-breed rotational dams had larger ($P < .01$) WHT than rotational calves from these dams. No differences between terminal vs rotational calves from four-breed rotational dams were observed for BWT, ADG, and WWT.

Chapter V

Genetic Effects

Introduction

Partitioning of effects such as direct (Ig) and maternal (Mg) additive genetic effects of breeds and direct (Ih) and maternal (Mh) heterotic genetic effects of breed combinations is necessary in order to design effective crossbreeding systems. These effects represent the primary genetic influences among the possible reasons for differences in performance of breed groups under given environmental conditions. The predictability and value of crossbreeding systems are enhanced if information is available about the genetic sources controlling important characters (Malik, 1984).

The estimates of the genetic effects were calculated as deviations from the overall least squares means by partial regression analysis. Direct additive effects were obtained for Angus (A), Brahman (B), Charolais (C), Gelbvieh (G), Hereford (H) and Simmental (S). Maternal additive effects were estimated for A, B, C, and H, while Ih and Mh were estimated for AB, AC, AH, BC, BH, and CH combinations.

Least Squares Analysis of Variance

Of the non-genetic sources of variation, sex of calf and the linear effects of cow age and Julian birth date were highly significant for all traits. The quadratic effect of cow age was significant for BWT, ADG and WWT. Least squares analysis of variance mean squares and significance levels of genetic effects on preweaning traits are presented in Table 5.1.

Table 5.1. Least squares analysis of variance mean squares and tests of significance for preweaning traits due to genetic effects

Source of variation[a,b]	df	BWT[c] (kg^2)	ADG (kg^2)	WWT (kg^2)	WHT (cm^2)
IgA	1	12.72	.101	5,462.0**	126.16**
IgB	1	17.87	.033	1,390.9	49.00
IgC	1	0.22	.001	36.4	17.30
IgG	1	33.30	.072*	3,553.0*	130.91**
IgS	1	3.53	.127**	6,579.4**	321.30**
IhAB	1	16.83	.109**	5,758.5**	156.64**
IhAC	1	3.41	.129**	6,350.8**	91.21*
IhAH	1	86.66	.046	2,648.4*	30.41
IhBC	1	8.51	.020	1,103.4	95.76*
IhBH	1	26.62	.031	1,632.1	48.89
IhCH	1	8.41	.022	1,043.3	29.32
MgA	1	33.28	.314**	15,058.5**	302.52**
MgB	1	1,614.17**	.845**	23,943.9**	764.59**
MgC	1	248.96**	.063*	4,242.0*	33.23

(table con'd.)

(Table 5.1 continued)

Source of variation[a,b]	df	BWT[c] (kg^2)	ADG (kg^2)	WWT (kg^2)	WHT (cm^2)
MhAB	1	142.90*	.317	16,904.9**	60.25
MhAC	1	0.23	.011	508.4	7.23
MhAH	1	47.15	.002	42.5	0.88
MhBC	1	31.43	.003	222.6	15.25
MhBH	1	83.63	.016	942.1	6.49
MhCH	1	18.56	.007	319.3	13.84
Residual mean square		32.27	14.34	667.7	18.18
Residual df		1,154.00	1,061	1,061	1,043
R^2 (%)		21.80	34.8	35.3	42.4
CV (%)		15.10	11.0	10.1	3.7

[a]Igi, Mgi = Breed direct and maternal additive effects for the ith breed in the progeny and dam, respectively. Ihi, Mhi = Breed direct and maternal heterotic effects for the ijth breed combination in the crossbred calf and dam, respectively.
[b]Breed codes: A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[c]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
*P < .05
**P < .01

Genetic Effects on Birth Weight

Direct and Maternal Additive Effects. Partial regression coefficients for direct and maternal additive effects are presented in Table 5.2 while selected breed contrast for these additive effects are presented in Table 5.3. Most maternal additive effects were significant for BWT while the direct additive effects were not. This reflects the importance of the maternal environment on prenatal growth. The MgB, MgC and MgH genetic effects on BWT were -5.02, 3.54 ($P < .01$) and 2.37 kg ($P < .05$), respectively. The MgB effect decreased BWT while MgC and MgH increased BWT. The MgB effect on BWT was 6.69 kg lower ($P < .01$) than the average of MgA, MgC and MgH effects. The negative MgB is common in the literature with means ranging from -9.0 to -4.2 kg (Roberson et al., 1986; Wyatt and Franke, 1986; Comerford et al., 1987; Olson et al., 1993). Additionally, Habet (1996) reported -4.16 kg for MgB for generations one to four of this project. These findings support the postulate of an inherent ability of B dams to suppress BWT. Therefore, in crossbreeding programs involving B the problem of calving difficulty may be circumvented by using B in the breed of dam.

The MgA effect on BWT was 3.26 kg lower ($P < .05$) than MgH. This value was similar to those of Alenda et al. (1980) and Neville et al. (1984). However Gaines et al. (1970) Gregory et al. (1978b), Wyatt and Franke (1986) and Habet (1996) reported no significant differences between MgA and MgH effects on BWT.

Table 5.2. Breed direct and maternal additive effects and standard errors for preweaning traits

Genetic effects	BWT[1] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
Direct additive (Ig)				
Angus	-2.65 ± 4.21	-.245 ± .090**	-57.04 ± 19.9**	-8.75 ± 3.3**
Brahman	5.59 ± 7.51	-.249 ± .159	-51.21 ± 35.45	-9.70 ± 5.9
Charolais	-0.49 ± 5.9	-.037 ± .128	-6.67 ± 28.5	-4.61 ± 4.7
Gelbvieh	1.53 ± 4.65	.230 ± .099*	50.88 ± 22.04*	9.84 ± 3.7**
Hereford	-8.98 ± 5.97	-.019 ± .128	-8.99 ± 28.5	-3.06 ± 4.7
Simmental	4.99 ± 4.91	.321 ± .103**	73.02 ± 23.24**	16.27 ± 3.9**
Maternal additive (Mg)				
Angus	-0.89 ± 0.88	-.092 ± .019**	-20.03 ± 4.2**	-2.90 ± 0**
Brahman	-5.02 ± 0.72**	.123 ± .015**	20.64 ± 3.4**	3.73 ± 0.6**
Charolais	3.54 ± 1.27**	.060 ± .027*	15.48 ± 6.1*	1.37 ± 1.0
Hereford	2.37 ± 1.00*	-.091 ± .022**	-16.09 ± 4.8**	-2.21 ± 0.8**

[1]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
*P < .05
**P < .01

Table 5.3. Estimated differences among selected breeds, in direct and maternal additive effects on preweaning traits

Breed contrasts[1,2]	BWT[3] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
Direct additive (Ig)				
C, G, S vs A, B, H	4.04 ± 6.70	.342 ± .150*	78.16 ± 33.3*	14.34 ± 5.50**
G, S vs A, B, C, H	4.89 ± 7.12	.423 ± .149**	92.91 ± 33.7**	19.59 ± 5.62**
B vs A, C, H	-9.63 ± 7.59	.148 ± .152	26.97 ± 35.8	4.22 ± 5.96
C vs A, H	5.33 ± 7.99	.950 ± .167	26.35 ± 38.2	1.30 ± 6.83
A vs H	6.34 ± 8.64	-.226 ± .184	-48.05 ± 40.9	-5.69 ± 6.83
S vs G	3.45 ± 1.09**	.091 ± .023**	22.14 ± 5.2*	6.43 ± 0.86**
Maternal additive (Mg)				
A, C, H vs B	6.69 ± 0.95**	-.163 ± .021*	-27.52 ± 4.6**	-4.97 ± 0.77**
C vs A, H	2.80 ± 1.88	.151 ± .051**	33.54 ± 9.1**	3.93 ± 1.51
A vs H	-3.26 ± 1.30*	-.001 ± .028	-3.95 ± 6.2	-0.69 ± 1.04

[1]Breed codes: A = Angus, B = Brahman, C = Charolais, G = Gelbvieh, H = Hereford, S = Simmental.
[2]Comparison between average of breeds represented in each group.
[3]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
*P < .05
**P < .01

The direct additive effects on BWT appeared to be similar for all breeds in this study. The values however, ranged from -8.98 for H to 5.59 kg for B. The lack of significance may be attributed to large standard errors associated with relatively small number of records contributing to the partial regression. Contrasts indicate that IgS for birth weight was 3.4 kg greater ($P < .01$) than IgG.

Direct and Maternal Heterotic Effects. Estimates of direct and materanal heterotic effects are in Tables 5.4, while selected breed combination contrasts are in Table 5.5. The heterotic effects for BWT appeared large but generally lacked significance. Although values of up to 6.99 kg were recorded, only the MhAB of 2.82 kg ($P < .05$) showed significance. Several researchers have found significant heterotic effects on BWT, especially for B crosses. Vaamonde and Franke (1984), Roberson et al.(1986), Wyatt and Franke (1986) and Olson et al. (1993) reported positive estimates for maternal heterotic influences on BWT for B crosses. However Habet (1996) reported -2.83, -3.86 and -2.40 kg for AB, CB and HB maternal heterotic effects, respectively.

Genetic Effects on Preweaning Average Daily Gain

Direct and Maternal Additive Effects. Estimates of the IgA and MgA genetic effects for ADG were -.245 and -.092 ($P < .01$) kg/d, respectively (Table 5.2). The MgH effect (-.091 kg; $P < .01$) was similar to the MgA effect for ADG. The IgH effect was not significant. No difference was reflected in the contrast between IgA

Table 5.4. Breed direct and maternal heterotic effects and standard errors for preweaning traits

Genetic effects	BWT[1] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
Direct heterotic (Ih)				
Angus x Brahman	3.90 ± 5.40	.329 ± .116**	75.42 ± 25.7**	12.53 ± 4.3**
Angus x Charolais	1.39 ± 4.27	.281 ± .091**	62.30 ± 20.2**	7.52 ± 3.4*
Angus x Hereford	6.99 ± 4.27	.169 ± .092	40.58 ± 20.3*	4.39 ± 3.4
Brahman x Charolais	3.06 ± 5.96	.157 ± .127	36.47 ± 28.3	10.81 ± 4.7*
Brahman x Hereford	5.47 ± 6.03	.196 ± .129	44.95 ± 28.7	7.85 ± 4.9
Charolais x Hereford	2.43 ± 4.76	.131 ± .103	28.41 ± 22.7	4.80 ± 3.8
Maternal heterotic (Mh)				
Angus x Brahman	2.82 ± 1.34*	.138 ± .024**	31.80 ± 6.3**	1.92 ± 1.1
Angus x Charolais	0.36 ± 4.30	-.083 ± .093	-18.07 ± 20.7	-2.17 ± 3.4
Angus x Hereford	4.29 ± 3.55	-.027 ± .075	-4.21 ± 16.7	0.61 ± 2.8
Brahman x Charolais	3.05 ± 3.09	.032 ± .067	8.53 ± 14.8	2.25 ± 2.5
Brahman x Hereford	4.49 ± 2.79	.064 ± .059	15.66 ± 13.2	1.32 ± 2.2
Charolais x Hereford	4.82 ± 6.85	-.099 ± .137	-21.06 ± 30.4	-4.41 ± 5.1

BWT = Birth weight, ADG = Average daily gain, WWT = Weaning weight (205 d), WHT = Weaning height.
*P < .05, **P < .01

Table 5.5. Estimated differences among selected breed combinations in direct and maternal heterotic effects for preweaning traits

Breed contrasts[1,2]	BWT[3] (kg)	ADG (kg)	WWT (kg)	WHT (cm)
Direct heterotic (Ih)				
AB, BC, BH, vs AH, AC, CH	0.54 ± 3.17	.034 ± .067	8.52 ± 15.0	4.83 ± 2.49
AB, BH vs BC	1.63 ± 5.00	.106 ± .109	23.70 ± 24.2	-0.62 ± 4.00
AB vs BH	-1.57 ± 5.24	.132 ± .112	30.45 ± 25.0	4.68 ± 4.18
AC, CH vs AH	-5.17 ± 2.88	.036 ± .061	4.77 ± 13.6	1.77 ± 2.27
AC vs CH	-1.04 ± 5.57	.149 ± .119	33.89 ± 26.35	2.72 ± 4.35
Maternal heterotic (Mh)				
AB, BC, BH, vs AH, AC, CH	0.30 ± 3.16	.148 ± .067*	33.11 ± 15.11*	3.82 ± 2.52
AB, BH vs BC	0.60 ± 2.89	.069 ± .063	15.19 ± 13.90	-0.63 ± 2.30
AB vs BH	-1.67 ± 2.75	.074 ± .059	16.15 ± 13.04	0.61 ± 2.18
AC, CH vs AH	-1.70 ± 4.77	.064 ± .103	-15.35 ± 22.92	-3.92 ± 3.80
AC vs CH	-4.46 ± 4.22	.015 ± .091	2.99 ± 20.29	2.24 ± 3.36

[1]Comparison between average of breed combinations indicated in each group.
[2]Breed combination codes: AB = Angus x Brahman, AC = Angus x Charolais, AH = Angus x Hereford, BC = Brahman x Charolais, BH = Brahman x Hereford, CH = Charolais x Hereford.
[3]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
*P < .05

and IgH effects. The difference between IgA and IgH of -.226 kg/d was associated with a standard error of .184 kg. No established pattern of relationship between IgA and IgH or between MgA and MgH was observed in the literature. Vaamonde and Franke (1984) and Koch et al. (1985) found that the estimates both of IgA and MgA were similar to direct effects of H, respectively. Gregory et al. (1978b) Dillard et al. (1980) and Morris et al. (1986) found a larger IgA effect on ADG relative to the IgH effects on ADG. Wyatt and Franke (1986) reported similar effect for IgA and IgH on ADG but an Angus maternal additive advantage of .041 kg/d on ADG. Habet (1996), for generation one to four of this project, also found a highly significant negative IgA (-.029 kg/d) and non significant IgH (.01 kg/d) on ADG as found in this report. However, the MgA effect in his report (-.017 kg/d) was not significant while the MgH effect was -.085 kg/d ($P < .01$), producing a MgA over MgH of .067 kg/d ($p < .01$).

IgG and IgS effects on ADG were .230 and .321 kg/d ($P < .01$), respectively. Wyatt and Franke (1996) also reported a large positive effect (.233 kg/d) for IgS on ADG. Contrasts reflect a superior ($P < .01$) transmitting ability for ADG of .091 kg/d for S over G on ADG.

The average direct additive effects on ADG of the Continental European breeds (C, G, and S) was .342 kg/d larger ($P < .05$) than the average Ig effect of A, B, and H (Table 5.3). The estimates for MgB and MgC effects for ADG were .123 ($P < .01$) and .060 kg/d ($P < .05$), respectively. Dillard et al. (1980) and Habet (1996) reported .048 and .13 kg/d ($P < .01$), respectively, for MgC which were comparable to the MgC estimate found in this study. The MgB effect on ADG was .163 kg/d greater ($P < .05$) than the mean MgA, MgC and MgH effects on ADG. The MgC effect on ADG was .151 kg/d greater ($P < .01$) than mean MgA and MgH effects on this trait.

Direct and Maternal Heterotic Effects. The estimates of IhAB and MhAB for ADG were .329 and .138 kg/d ($P < .01$), respectively (Table 5.4). Positive IhAB values for ADG were also reported by Vaamonde and Franke (1984), Wyatt and Franke (1986), and Habet (1996), although their values were smaller (.10 to .23 kg/d). The estimate of MhAB from this study was also larger than the .09 and .05 kg/d reported by Vaamonde and Franke (1984) and Wyatt and Franke (1986), respectively. Habet (1996) reported an estimate of -.025 kg/d ($P < .05$) for MhAB which is in contrast with results in this study. The IhAB and MhAB effects were the largest of the heterotic effects on ADG. This trend agrees with the results of Wyatt and Franke (1986) for similar breed combinations. In addition, contrasts revealed that the average maternal heterotic effects of B crosses was .148kg/d greater ($P < .05$) than the average maternal heterotic effects of non-B crosses. The direct heterotic effect of the AC combination on ADG was .281 kg/d ($P < .01$). This was larger than the .163 kg/d reported by Habet (1996) for generations one through four. In contrast, however, Dillard at al (1980) and Wyatt and Franke (1986) reported non-significant IhAC estimates for ADG.

All direct heterotic effects on ADG were positive, though only IhAB and IhAC were significant. With the exception of the positive and significant MhAB effect, all maternal heterotic effects were non-significant and some were negative. Most other reports showed positive and significant Mh effects for breed combinations found in this study.

Genetic Effects on Weaning Weight.

Direct and Maternal Additive Effects. Both IgA and MgA in this study were shown to decrease WWT with estimates of -57.05 and -20.03 kg (P < .01), respectively (Table 5.2). The IgH effect on WWT (-8.99 kg) was not different from zero, while the MgH effect on WWT was -16.06 kg (P < .01). Habet (1996) also reported a negative IgA (-10.21 kg; P < .01) but found a non-significant MgA effect (-.017 kg) on WWT. The relationship between IgH (-3.95 kg) and MgH (-15.90 kg; P < .01) in his study was similar to results in this report. Results of the contrasts suggest no significant difference between IgA and IgH nor between MgA and MgH. Alenda et al. (1980), and Wyatt and Franke (1986) reported a positive IgH for WWT, compared to IgA. In contrast, MacNeil et al. (1982) reported that IgH decreased WWT relative to IgA.

There was a negative but non-significant IgB effect on WWT while the MgB effect (20.64 kg) increased (P < .01) WWT. Wyatt and Franke (1986) also reported non significant IgB and positive MgB (3.7kg P < .01) effects on WWT. Other reports published positive MgB effects on WWT, but most were not as large as these values.

Peacock et al. (1981) and Habet (1996) reported an IgB on WWT of 3.00 and 6.78 kg ($P < .01$), respectively. The MgC effect on WWT was 16.45 kg. Similar values were reported by Alenda et al. (1980), McNeil et al. (1982), and Habet (1986). The MgC effect on WWT was 33.54 kg greater than the average of MgA and MgH effects.

The negative IgC effect on WWT was not significantly different from zero. Large significant IgC effects (12 to 42 kg; $P < .01$) were found in other reports (Alenda et al. 1980; Peacock et al. 1981; MacNeil et al. 1982; Wyatt and Franke 1986; Habet 1996). The result in this report is probably due to the presence of G and S in the partitioning of direct additive effects.

The IgG and IgS effects for WWT were estimated at 50.88 kg ($P < .05$) and 73.03 kg ($P < .01$), respectively. The IgS effect on WWT exceeded ($P < .05$) IgG by 22.14 kg.

Direct and Maternal Heterotic Effects. All Ih effects on WWT were positive, though not all were significantly different from zero. The Mh effects of B crosses on WWT were positive and all other Mh effects were negative. Estimates of IhAB and MhAB were 75.42 and 31.80 kg ($P < .01$), respectively, and were much larger than those reported in other studies (Peacock et al. 1981; Wyatt and Franke, 1986). Habet (1990) found a smaller positive IhAB (7.96 kg) and a negative MhAB (-7.7 kg) effect on WWT.

The AC combination was the only one involving C that had a significant estimate for direct heterotic effect on WWT. The estimate of IhAC on WWT was

62.3 kg ($P < .01$). This was larger than the 32.82 kg($P < .01$) reported by Habet (1996) while other researchers found that the IhAC effect did not significantly increase WWT (Alenda et al. 1980; Peacock et al. 1981; Wyatt and Franke, 1986). The MhAC effect of -18.1 kg was not significant. This was similar to the results of Alenda et al. (1980) and Wyatt and Franke (1986), although they had smaller negative and positive estimates, respectively. Habet (1996) found that MhAC decreased ($P < .01$) WWT by 26.4 kg.

The IhAH effect increased WWT by 40.58kg ($P < .05$). Positive IhAH effects on WWT were reported in other studies but not of this magnitude. Highly significantly IhAH effects of 6.1, 6.9, 4.8 and 20.7 kg were reported by Vaamonde and Franke (1984), Koch et al. (1985), Wyatt and Franke (1986), and Habet (1996), respectively.

Most studies showed significant IhBC and IhBH direct heterotic effects (Peacock et al., 1978; Vaamonde and Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986; Habet, 1996). The estimates of IhBC and IhBH on WWT in this study were 36.47 and 44.95 kg, respectively. These were close to the values reported by Habet (1996) and larger than the estimates of the other researchers.

As with the direct heterotic effects, the maternal heterotic effects of BC and BH on WWT were not different for zero. Habet (1996) reported non-significant and small MhBC and MhBH. In other reports MhBC and MhBH effects on WWT were highly significant ranging 17.7 to 28.2 kg (Peacock et al., 1981; Vaamonde and

Franke, 1984; Roberson et al., 1986; Wyatt and Franke, 1986). Contrasts of the heterotic effects for WWT showed a maternal advantage ($P < .05$) for B combinations of 33.1 kg over other crosses (Table 5.5).

Genetic Effects on Hip Height

Direct and Maternal Additive Effects. The least squares mean hip height for calves in this study was 117.07 cm. The estimates of IgG and IgS on WHT were positive while all other direct additive effects were negative, though not all were significant. The IgG and IgS effects were 9.84 and 16.27 cm ($P < .01$), respectively. This is indicative of superior transmitting abilities of G and S breeds for WHT over the other breeds in the study. The IgS effect was 6.43 cm greater($P < .01$) than the IgG effect for WHT. The direct additive effects of A, B, C, and H on WHT were -8.75($P < .01$), -9.70, -4.61, and -3.06 cm, respectively. The IgA effect significantly reduced WHT while the Ig effects of B, C and H were not significantly different of zero. Baker et al. (1989) reported breed deviations from the overall mean WHT of -2.8, 2.9 and 4.3 cm, for A, B, and H, respectively.

Results of contrasts show that the direct additive effects of the Continental European breeds (C, G and S) on WHT were 14.34 cm greater ($P < .01$) than direct additive effects of non-continental breeds (A, B, and H). Additionally, the average Ig on WHT of the terminal sire of breeds (G and S) exceeded ($P < .01$) the average Ig on WHT of the rotation breeds (A, B, C, and H) by 19.59 cm.

The maternal additive genetic effects on WHT of A, B, and H were -2.90, 3.73 and -2.21 cm ($P < .01$) respectively. The MgB increased WHT while MgA and MgH effects decreased WHT. The MgC effect of 1.37 cm was not different from zero. Sacco et al. (1989) reported on diallel matings involving Angus, Brahman, Hereford, Holstein and Jersey dams and found that Hereford dams weaned the shortest calves. In this study the contrasts showed non-significant differences between MgA and MgH effects on WHT, while the MgB effect was 4.97 cm larger than the average of A, C, and H maternal additive effects. This is further evidence of the positive influence of Brahman dams on preweaning growth traits of calves. Brown et al. (1993) reported an interaction of maternal effects with forage environment. Calves on A dams received a maternal advantage ($P < .01$) on bermudagrass over calves on B dams but the maternal effects of the two breeds were similar on tall fescue.

Direct and Maternal Heterotic Effects. The direct heterotic effects on WHT were all positive though some lacked statistical significance. The IhAB, IhAC and IhBC effects increased WHT by 12.53 ($P < .01$), 7.52 and 10.81 cm ($P < .05$), respectively. Of the significant direct heterotic effects, those involving B had the larger values. This is consistent with the trend for the other preweaning growth traits. The direct heterotic effects of AH, BH and CH were 4.39, 7.85 and 4.80 cm, respectively, but they were not significantly different from zero.

The maternal heterotic effects on WHT all lacked statistical significance. The Mh effects of AB, AH, BC and BH were positive while the effects for AC and CH were negative. The larger maternal heterotic estimates were for the B cross dams. Brown et at. (1993) reported an MhAB of 2.7 cm on bermudagrass and 1.7 cm on tall fescue.

Summary

The IgA and MgA effects decreased ADG, WWT, and WHT relative to the other breeds evaluated for the respective effects. The estimates for IgA were -.24, -57.04 kg and -8.75 cm ($P < .01$) for ADG, WWT, and WHT, respectively; while corresponding estimates for MgA were -.092, -20.03 kg, and -2.90 cm. The MgB effects decreased BWT and increased ADG, WWT and WHT, the respective estimates being -5.02, .123, 20.64 kg, and 3.73 cm ($P < .01$). The MgC effects were 3.54 ($P < .01$), .060 and 15.48 kg ($P < .05$) for BWT, ADG and WWT. The MgH effects increased BWT (2.37 kg; $P < .05$) and decreased ($P < .01$) ADG (-.091 kg), WWT (-16.04 kg), and WHT (-2.21 cm). The MgB effect on BWT was lower ($P < .01$) than the average Mg effects of A, C, and H on BWT. For ADG, WWT and WHT, MgB exceeded the average of MgA, MgC and MgH by .163 ($P < .05$), 27.52 kg and 4.97 cm ($P < .01$), respectively.

The IgG and IgS effects increased all preweaning traits except BWT. The IgS effects exceeded IgG effects by .091 ($P < .01$) and 22.14 kg ($P < .05$), and 6.43 cm ($P < .01$) for ADG, WWT and WHT, respectively.

Angus x B direct heterotic effects produced increases ($P < .01$) in ADG (.329 kg), WWT (75.4 kg), and WHT (12.53 cm), while MhAB affects increased BWT

(2.82 kg; $P < .05$), ADG (.138 kg; $P < .01$) and WWT (31.8 kg; $P < .01$). IhAC effects on ADG, WWT, and WHT were .281, 62.3 kg ($P < .01$) and 7.53 cm ($P < .05$). IgAH effect on WWT was 40.54 kg ($P< .05$), while IgBC for WHT was 10.8 cm ($P < .05$).

Chapter VI

Conclusions

The objective of crossbreeding is to exploit between breed genetic variation. However, potential benefits can only be realized with proper planning and selection of the best breeds and mating systems to fit the objectives.

The maternal environment provided by crossbred dams was more conducive to preweaning growth than that of their straightbred contemporaries. This was reflected in higher ADG and WWT for calves from crossbred vs purebred dams. One exception was that four-breed rotational dams produced calves with means similar to purebred dams for these traits.

Progeny of two-breed rotational dams had larger means for ADG, WWT, and WHT than the calves from three- and four-breed rotational dams, for both rotational and terminal mating systems. Initially this might suggest that it is not necessary to have more than two breeds in a rotational system. However, Habet (1996) found three- and four-breed rotations to be more favorable for these traits. Additionally, three-breed terminal calves had similar means to two-breed rotational-terminal calves for the above mentioned traits, which were larger than the means for all other mating systems.

Since heterosis is largely a function of dominance, and is therefore directly correlated with breed heterozygosity, it appears that the sources of paired genes is as important as the mating system in determining the level of performance. Evidence from this study confirms the desirable influence of Brahman breeding in this regard. The premise of this observation will be demonstrated in the following paragraph.

The two-breed rotational dams and their progeny had the highest level of Brahman breeding among all crossbred dams and their calves, followed by three-breed terminal dams and their calves. Progeny of two-breed rotational dams and three-breed terminal calves had 66% and 50% breed heterozygosity, respectively, coming from Brahman genes paired with genes from another breed. Additionally, they benefitted from 66% and 100% heterozygosity, respectively from Brahman paired genes in their dams. In contrast, three- and four-breed rotational dams had 56% Brahman paired heterozygosity, and their progeny in turn had 28%. Progeny of four-breed rotational dams had the lowest means overall for most traits, and they had the lowest level of Brahman breeding.

The importance of the maternal contribution was also highlighted in the partitioning of the genetic effects. Maternal effects are environmental in terms of their influence on the calf, but they are determined by the genes of the dam as well as the environmental conditions to which she is subjected. Most Mg effects were significant sources of variation in the traits studied. The MgB effect for birth weight was the lowest of the Mg effects for this trait, while the MgC was the largest. In phenotypic terms this was expressed as lower birth weights for calves from B dams and higher birth weights for calves from C dams. Large birth weights are directly related to the incidence of dystocia, therefore low BWT is more desirable, provided that it stays above the threshold level for survival.

For ADG, WWT and WHT, the MgB effects were positive while the MgA and MgH effects were negative. The MgC effects for ADG and WWT were positive but lower than the MgB effects for these traits. These results illustrate the superior maternal capability of the B.

The beef industry in Louisiana is primarily cow-calf production, thus the performance of animals for preweaning traits is important. The information provided in this report, is an additional contribution to the scientific information base which provides guidelines for producers, who have to make decisions based on their resources, market conditions, and preferences.

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Appendix

The following tables are the results of the analyses of data for each dam breed type. The significance levels were summarized in Table 4.2.

Table A.1. Least squares analysis of variance mean squares (MS) for preweaning traits among first-cross (F_1) calves

	BWT[a] (kg^2)		ADG (kg^2)		WWT (kg^2)		WHT (cm^2)	
Sources of variation	df	MS	df	MS	df	MS	df	MS
Sex of calf	1	165.5*	1	.149**	1	7,857.4**	1	139.2**
Mating type (MT)	3	49.6	3	.133**	3	6,207.7**	3	418.2**
Sire:MT	68	55.7**	63	.029**	63	1,229.7**	63	29.9**
Julian birth date	1	0.74	1	.017	1	660.2	1	352.6**
Cow age, Linear	1	230.7**	1	.104**	1	6,327.0**	1	26.5
Cow age, Quadratic	1	236.1**	1	.104**	1	6,424.9**	1	25.5
Year, Linear	1	3.2	1	.003	1	264.1	1	13.4
Year, Quadratic	1	2.8	1	.003	1	269.5	1	13.6
Residual	132	25.3	114	.011	114	577.9	109	15.3
R^2 (%)		63.7		76.5		74.8		79.7
CV (%)		13.0		10.5		9.8		3.5

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
* P < .05
**P < .01

Table A.2. Least squares analysis of variance mean squares (MS) for preweaning traits among three-breed terminal calves

	BWT[a] (kg^2)		ADG (kg^2)		WWT (kg^2)		WHT (cm^2)	
Sources of variation	df	MS	df	MS	df	MS	df	MS
Sex of calf	1	100.9	1	.101**	1	5,161.5**	1	100.3**
Mating type (MT)	2	107.2*	2	.262	2	1,965.7*	2	190.7**
Sire:MT	86	49.9*	82	.013	82	706	81	22.5**
Julian birth date	1	209.1*	1	.011	1	1,189	1	259.6**
Cow age, Linear	1	29.0	1	.075**	1	4060.3*	1	29.7
Cow age, Quadratic	1	7.6	1	.068*	1	3,490.0*	1	22.1
Year, Linear	1	350.8**	1	.001	1	276.6	1	0.62
Year, Quadratic	1	355.0**	1	.001	1	297.8	1	0.55
Residual	178	33.0	159	.010	159	527.0	155	14.2
R^2 (%)		53.4		56.0		58.1		59.5
CV (%)		15.2		9.2		8.7		3.3

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
* $P < .05$
**$P < .01$

Table A.3. Least squares analysis of variance mean squares (MS) for preweaning traits among progeny of two-breed rotational dams

	BWT[a] (kg^2)		ADG (kg^2)		WWT (kg^2)		WHT (cm^2)	
Sources of variation	df	MS	df	MS	df	MS	df	MS
Sex of calf	1	122.5*	1	.022	1	414.7	1	111.5**
Line (LN)	2	55.4	2	.002	2	177.8	2	53.3*
Mating system (MSY)	1	29.7	1	.144**	1	6,840.2**	1	344.7**
LN x MSY	2	17.5	2	.002	2	57.6	2	36.2
Sire: LN x MSY	102	29.7	101	.015	101	721.2	101	26.4**
Cow age, Linear	1	14.5	1	.028	1	1,849.9	1	67.2*
Cow age, Quadratic	1	0.2	1	.022	1	1,241.3	1	55.3*
Julian birth date	1	23.9	1	.042	1	1,968.2	1	324.2**
Year, Linear	1	1.0	1	.069*	1	2,774.0*	1	79.7*
Year, Quadratic	1	0.9	1	.070*	1	2,816.8*	1	79.0*
Residual	158	28.4	143	.013	143	618.6	140	13.4
R^2 (%)		53.6		58.1		59.1		71.5
CV (%)		14.5		10.5		9.6		3.2

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
* $P < .05$
** $P < .01$

Table A.4. Least squares analysis of variance mean squares for preweaning traits among progeny of three-breed rotational dams

	BWT[a] (kg^2)		ADG (kg^2)		WWT (kg^2)		WHT (cm^2)	
Sources of variation	df	MS	df	MS	df	MS	df	MS
Sex of calf	1	217.2**	1	.177**	1	9,930.7**	1	123.5**
Line (LN)	2	147.1**	2	.081**	2	4,669.0**	2	147.4**
Mating System (MSY)	1	49.9	1	.001	1	33.4	1	292.2**
LN x MSY	2	51.8	2	.022	2	1,004.6	2	9.1
Sire: LN x MSY	123	29.9	122	.016**	122	775.6**	122	23.3**
Cow age, Linear	1	0.4	1	.148**	1	6,743.7**	1	0.4
Cow age, Quadratic	1	0.2	1	.092**	1	4,420.8**	1	0.3
Julian birth date	1	28.6	1	.015	1	593.8	1	377.4**
Year, Linear	1	133.1*	1	.005	1	39.2	1	11.1
Year, Quadratic	1	129.0*	1	.004	1	33.6	1	11.1
Residual	196	30.0	177	.010	177	494.8	133	13.8
R^2 (%)		52.7		69.9		70.2		71.0
CV (%)		14.2		9.4		8.8		3.3

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
* P < .05
**P < .01

Table A.5. Least squares analysis of variance mean squares for preweaning traits among progeny of four-breed rotational dams

	BWT[a] (kg^2)		ADG (kg^2)		WWT (kg^2)		WHT (cm^2)	
Sources of variation	df	MS	df	MS	df	MS	df	MS
Sex of calf	1	15.5	1	.032	1	1,410.8	1	11.4
Mating System (MSY)	1	0.1	1	.005	1	324.8	1	226.0**
Sire: MSY	36	28.6	34	.017	34	779.0	34	25.2
Cow age, Linear	1	2.7	1	.053	1	2,774.9*	1	4.4
Cow age, Quadratic	1	21.9	1	.061*	1	2,827.4*	1	1.7
Julian birth date	1	210.5**	1	.046	1	1,352.6	1	228.2**
Year, Linear	1	52.7	1	.079*	1	2,923.3*	1	69.4
Year, Quadratic	1	52.5	1	.080*	1	2,942.2*	1	69.3
Residual	50	23.0	41	.014	41	582.4	38	23.5
R^2 (%)		64.0		62.6		66.2		71.1
CV (%)		13.0		11.5		9.8		4.3

[a]BWT = birth weight, ADG = average daily gain, WWT = weaning weight (205 d), WHT = weaning height.
* P < .05
**P < .01

Vita

Dian Allison Williams was born in Port Antonio, Jamaica, on May 17, 1957. She is the daughter of Fastina Horne and Evan Tomlinson and was raised by Miss Ida Scott, since her parents migrated to England in 1960. Her early education was received at Norwich Basic, Norwich Primary, and Ticthfield High Schools. After High School, she worked as a Library Assistant at the Portland Parish Library. She attended the Jamaica School of Agriculture where she earned an Associate degree in Agricultural Sciences in December, 1980. Dian worked as a Research Assistant at the Bodles Agricultural Research Station, from January to August, 1981. She proceeded to the University of the West Indies where she earned a bachelor of science degree in Agricultural Sciences, in 1983. She then returned to Bodles as a Junior Research Officer from 1983 to 1986. In 1986 she was employed by the College of Agriculture. While at the college she was awarded a scholarship through the United States Agency for International Development in 1987 to pursue the master's degree in Animal Sciences which she earned at Louisiana State University. On completion, she returned to the College of Agriculture as a lecturer in Animal Sciences. In 1995 she embarked on studies leading to a doctorate in Animal Breeding and Genetics. Dian is married to Errol George Medley. She has two sons Kevin, age 13 and Romario, age 3.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Dian Allison Williams

Major Field: Animal and Dairy Sciences

Title of Dissertation: Mating System Differences and Genetic Effects for Preweaning Traits in Beef Cattle in the Gulf Coast Region of the United States

Approved:

D E Franke

Major Professor and Chairman

John M Larkin

Dean of the Graduate School

EXAMINING COMMITTEE:

K. E. Hoyt

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Date of Examination:

June 18, 1998

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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